A

INSTITUTION

OF

MECHANICAL ENGINEERS.

ESTABLISHED 1847.

PROCEEDINGS.

1896.

PARTS 1–2.

PUBLISHED BY THE INSTITUTION,
19 VICTORIA STREET, WESTMINSTER, S.W.

CONTENTS.

1896.

PARTS 1–2.

PAST-PRESIDENTS.

George Stephenson, 1847–48. (*Deceased* 1848.)

Robert Stephenson, F.R.S., 1849–53. (*Deceased* 1859.)

Sir William Fairbairn, Bart., LL.D., F.R.S., 1854–55. (*Deceased* 1874.)

Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856–57, 1866. (*Deceased* 1887.)

John Penn, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)

James Kennedy, 1860. (*Deceased* 1886.)

The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861–62, 1869.

Robert Napier, 1863–65. (*Deceased* 1876.)

John Ramsbottom, 1870–71.

Sir William Siemens, D.C.L., LL.D., F.R.S., 1872–73. (*Deceased* 1883.)

Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S., 1874–75.

Thomas Hawksley, F.R.S., 1876–77. (*Deceased* 1893.)

John Robinson, 1878–79.

Edward A. Cowper, 1880–81. (*Deceased* 1893.)

Percy G. B. Westmacott, 1882–83.

Sir Lowthian Bell, Bart., F.R.S., 1884.

Jeremiah Head, 1885–86.

Sir Edward H. Carbutt, Bart., 1887–88.

Charles Cochrane, 1889.

Joseph Tomlinson, 1890–91. (*Deceased* 1894.)

William Anderson, C.B., D.C.L., F.R.S., 1892–93.

Alexander B. W. Kennedy, LL.D., F.R.S., 1894–95.

OFFICERS.

1896.

PRESIDENT.

E. Windsor Richards,	Low Moor.

PAST-PRESIDENTS.

William Anderson, C.B., D.C.L., F.R.S.,	Woolwich.
The Rt. Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S.,	Newcastle-on-Tyne.
Sir Lowthian Bell, Bart., F.R.S.,	Northallerton.
Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S.,	London.
Sir Edward H. Carbutt, Bart.,	London.
Charles Cochrane,	Stourbridge.
Jeremiah Head,	London.
Alexander B. W. Kennedy, LL.D., F.R.S.,	London.
John Ramsbottom,	Alderley Edge.
John Robinson,	Leek.
Percy G. B. Westmacott,	Newcastle-on-Tyne.

VICE-PRESIDENTS.

Sir Douglas Galton, K.C.B., D.C.L., LL.D., F.R.S.,	London.
Samuel W. Johnson,	Derby.
Francis C. Marshall,	Newcastle-on-Tyne.
Edward P. Martin,	Dowlais.
William H. Maw,	London.
J. Hartley Wicksteed,	Leeds.

MEMBERS OF COUNCIL.

John A. F. Aspinall,	Horwich.
Henry Davey,	London.
William Dean,	Swindon.
Benjamin A. Dobson,	Bolton.
Bryan Donkin,	London.
John Hopkinson, Jun., D.Sc., F.R.S.,	London.
Arthur Keen,	Birmingham.
William Laird,	Birkenhead.
John G. Mair-Rumley,	London.
Henry D. Marshall,	Gainsborough.
Thomas Mudd,	West Hartlepool.
James Platt,	Gloucester.
T. Hurry Riches,	Cardiff.
A. Tannett Walker,	Leeds.
Sir William H. White, K.C.B., LL.D., F.R.S.,	London.

TREASURER.

Harry Lee Millar.

SECRETARY.

Alfred Bache,

Institution of Mechanical Engineers, 19 *Victoria Street*, *Westminster*, *S.W.*

[Telegraphic address:—*Mech*, *London*. Telephone, 3264.]

THE INSTITUTION OF MECHANICAL ENGINEERS.

Memorandum of Association.

August 1878.

1st. The name of the Association is "The Institution of Mechanical Engineers."

2nd. The Registered Office of the Association will be situate in England.

3rd. The objects for which the Association is established are :—

(a.) To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the Members of the Institution and to the community at large.

(b.) To enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information on such subjects.

(c.) To acquire and dispose of property for the purposes aforesaid.

(d.) To do all other things incidental or conducive to the attainment of the above objects or any of them.

4th. The income and property of the Association, from whatever source derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly, by way of dividend, bonus, or otherwise howsoever, by way of profit to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them: Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any Member of the Association, or other person, in return for any services rendered to the Association, or prevent the giving of privileges to the Members of the Association in attending the meetings of the Association, or prevent the borrowing of money (under such powers as the Association and the Council thereof may possess) from any Member of the Association, at a rate of interest not greater than five per cent. per annum.

5th. The fourth paragraph of this Memorandum is a condition on which a licence is granted by the Board of Trade to the Association in pursuance of Section 23 of the Companies Act 1867. For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which shall be duly observed by the Association.

6th. If the Association act in contravention of the fourth paragraph of this Memorandum, or of any such further conditions, the liability of every Member of the Council shall be unlimited; and the liability of every Member of the Association who has received any such dividend, bonus, or other profit as aforesaid, shall likewise be unlimited.

7th. Every Member of the Association undertakes to contribute to the Assets of the Association in the event of the same being wound up during the time that he is a Member, or within one

year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a Member, and of the costs, charges, and expenses for winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding Five Shillings, or in case of his liability becoming unlimited such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

8th. If upon the winding up or dissolution of the Association there remains, after the satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the Members of the Association, but shall be given or transferred to some other Institution or Institutions having objects similar to the objects of the Association, to be determined by the Members of the Association at or before the time of dissolution; or in default thereof, by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter.

Articles of Association.

FEBRUARY 1893.

INTRODUCTION.

Whereas an Association called "The Institution of Mechanical Engineers" existed from 1847 to 1878 for objects similar to the objects expressed in the Memorandum of Association of the Association (hereinafter called "the Institution") to which these Articles apply;

And whereas the Institution was formed in 1878 for furthering and extending the objects of the former Institution, by a registered Association, under the Companies Acts 1862 and 1867;

And whereas terms used in these Articles are intended to have the same respective meanings as they have when used in those Acts, and words implying the singular number are intended to include the plural number, and *vice versâ*;

NOW THEREFORE IT IS HEREBY AGREED as follows:—

CONSTITUTION.

1. For the purpose of registration the number of members of the Institution is unlimited.

MEMBERS, ASSOCIATE MEMBERS, GRADUATES, ASSOCIATES, AND HONORARY LIFE MEMBERS.

2. The present Members of the Institution, and such other persons as shall be admitted in accordance with these Articles, and none others, shall be Members of the Institution, and be entered on the register as such.

3. Any person may become a Member of the Institution who shall be qualified and elected as hereinafter mentioned, and shall agree to become such Member, and shall pay the entrance fee and first subscription accordingly.

4. The qualification of Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

5. The election of Members shall be conducted as prescribed by the By-laws from time to time in force, as provided by the Articles.

6. In addition to the persons already admitted as Graduates, Associates, and Honorary Life Members respectively, the Institution may admit such persons as may be qualified and elected in that behalf as Associate Members, Graduates, Associates, and Honorary Life Members respectively of the Institution, and may confer upon them such privileges as shall be prescribed by the By-laws from time to time in force, as provided by the Articles: provided that no Associate Member, Graduate, Associate, or Honorary Life Member shall be deemed to be a Member within the meaning of the Articles.

7. The qualification and mode of election of Associate Members, Graduates, Associates, and Honorary Life Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

8. The rights and privileges of every Member, Associate Member, Graduate, Associate, or Honorary Life Member shall be personal to himself, and shall not be transferable or transmissible by his own act or by operation of law.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. The Entrance Fees and Subscriptions of Members, Associate Members, Graduates, and Associates shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

EXPULSION.

10. If any Member, Associate Member, Graduate, or Associate shall leave his subscription in arrear for two years, and shall fail to pay such arrears within three months after a written application has been sent to him by the Secretary, his name may be struck off the register by the Council at any time afterwards, and he shall thereupon cease to have any rights as a Member, Associate Member, Graduate, or Associate, but he shall nevertheless continue liable to pay the arrears of subscription due at the time of his name being so struck off: provided always that this regulation shall not be construed to compel the Council to remove any name, if they shall be satisfied the same ought to be retained.

11. The Council may refuse to continue to receive the subscriptions of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall in the opinion of the Council have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution; and may remove his name from the register, and he shall thereupon cease to be a Member, Associate Member, Graduate, or Associate (as the case may be) of the Institution.

GENERAL MEETINGS.

12. The General Meetings shall consist of the Ordinary Meetings, the Annual General Meeting, and of Special Meetings as hereinafter defined.

13. The Annual General Meeting shall take place in London in one of the first four months of every year. The Ordinary Meetings shall take place at such times and places as the Council shall determine.

14. A Special Meeting may be convened at any time by the Council, and shall be convened by them whenever a requisition signed by twenty Members or Associate Members of the Institution,

specifying the object of the Meeting, is left with the Secretary. If for fourteen days after the delivery of such requisition a Meeting be not convened in accordance therewith, the Requisitionists or any twenty Members or Associate Members of the Institution may convene a Special Meeting in accordance with the requisition. All Special Meetings shall be held in London.

15. Seven clear days' notice of every Meeting, specifying generally the nature of any special business to be transacted at any Meeting, shall be given to every person on the register of the Institution, except as provided by Article 35, and no other special business shall be transacted at such Meeting; but the non-receipt of such notice shall not invalidate the proceedings of such Meeting. No notice of the business to be transacted (other than such ballot lists as may be requisite in case of elections) shall be required in the absence of special business.

16. Special business shall include all business for transaction at a Special Meeting, and all business for transaction at every other Meeting, with the exception of the reading and confirmation of the Minutes of the previous Meeting, the election of Members, Associate Members, Graduates, and Associates, and the reading and discussion of communications as prescribed by the By-laws, or by any regulations of the Council made in accordance with the By-laws.

PROCEEDINGS AT GENERAL MEETINGS.

17. Twenty Members or Associate Members shall constitute a quorum for the purpose of a Meeting other than a Special Meeting. Thirty Members or Associate Members shall constitute a quorum for the purpose of a Special Meeting.

18. If within thirty minutes after the time fixed for holding the Meeting a quorum is not present, the Meeting shall be dissolved, and all matters which might, if a quorum had been present, have been done at a Meeting (other than a Special Meeting) so dissolved, may forthwith be done on behalf of the Meeting by the Council.

19. The President shall be Chairman at every Meeting, and in his absence one of the Vice-Presidents; and in the absence of all Vice-Presidents a Member of Council shall take the chair; and if no Member of Council be present and willing to take the chair, the Meeting shall elect a Chairman.

20. The decision of a General Meeting shall be ascertained by show of hands, unless, after the show of hands, a poll is forthwith demanded; and by a poll, when a poll is thus demanded. The manner of taking a show of hands or a poll shall be in the discretion of the Chairman; and an entry in the Minutes, signed by the Chairman, shall be sufficient evidence of the decision of the General Meeting. Each Member and Associate Member shall have one vote and no more. In case of equality of votes the Chairman shall have a second or casting vote: provided that this Article shall not interfere with the provisions of the By-laws as to election by ballot.

21. The acceptance or rejection of votes by the Chairman shall be conclusive for the purpose of the decision of the matter in respect of which the votes are tendered: provided that the Chairman may review his decision at the same Meeting, if any error be then pointed out to him.

BY-LAWS.

22. The By-laws set forth in the schedule to these Articles, and such altered and additional By-laws as shall be substituted or added as hereinafter mentioned, shall regulate all matters by the Articles left to be prescribed by the By-laws, and all matters which consistently with the Articles shall be made the subject of By-laws. Alterations in, and additions to, the By-laws, may be made only by resolution of the Members and Associate Members at an Annual General Meeting, after notice of the proposed alteration or addition has been announced at the previous Ordinary Meeting, and not otherwise.

COUNCIL.

23. The Council of the Institution shall be chosen from the Members only, and shall consist of one President, six Vice-Presidents, fifteen ordinary Members of Council, and of the Past-Presidents. The President, two Vice-Presidents, and five Members of Council (other than Past-Presidents), shall retire at each Annual General Meeting, but shall be eligible for re-election. The Vice-Presidents and Members of Council to retire each year shall, unless the Council agree among themselves, be chosen from those who have been longest in office, and in cases of equal seniority shall be determined by ballot.

24. The election of a President, Vice-Presidents, and Members of Council, to supply the place of those retiring at the Annual General Meeting, shall be conducted in such manner as shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

25. The Council may supply any casual vacancy in the Council (including any casual vacancy in the office of President) which shall occur between one Annual General Meeting and another; and the President, Vice-Presidents, or Members of Council so appointed by the Council shall retire at the succeeding Annual General Meeting. Vacancies not filled up at any such Meeting shall be deemed to be casual vacancies within the meaning of this Article.

OFFICERS.

26. The Treasurer, Secretary, and other employés of the Institution shall be appointed and removed in the manner prescribed by the By-laws from time to time in force, as provided by the Articles. Subject to the express provisions of the By-laws, the officers and servants of the Institution shall be appointed and removed by the Council.

27. The powers and duties of the officers of the Institution shall, subject to any express provision in the By-laws, be determined by the Council.

POWERS AND PROCEDURE OF COUNCIL.

28. The Council may regulate their own procedure, and delegate any of their powers and discretions to any one or more of their body, and may determine their own quorum: if no other number is prescribed, three members of Council shall form a quorum.

29. The Council shall manage the property, proceedings, and affairs of the Institution, in accordance with the By-laws from time to time in force.

30. The Treasurer may, with the consent of the Council, invest in the name of the Institution any moneys not immediately required for the purposes of the Institution in or upon any of the following investments (that is to say):—

(A) The Public Funds, or Government Stocks of the United Kingdom, or of any Foreign or Colonial Government guaranteed by the Government of the United Kingdom.

(B) Real or Leasehold Securities, or in the purchase of real or leasehold properties in Great Britain or Ireland.

(C) Debentures, Debenture Stock, or Guaranteed or Preference Stock, of any Company incorporated by special Act of Parliament, the ordinary Shareholders whereof shall at the time of such investment be in actual receipt of half-yearly or yearly dividends.

(D) Stocks, Shares, Debentures, or Debenture Stock of any Railway, Canal, or other Company, the undertaking whereof is leased to any Railway Company at a fixed or fixed minimum rent.

(E) Stocks, Shares, or Debentures of any East Indian Railway or other Company, which shall receive a contribution from Her Majesty's East Indian Government of a fixed annual percentage on their capital, or be guaranteed a fixed annual dividend by the same Government.

(F) The security of rates levied by any corporate body empowered to borrow money on the security of rates, where such borrowing has been duly authorised by Act of Parliament.

31. The Council may, with the authority of a resolution of the Members and Associate Members in General Meeting, borrow moneys for the purposes of the Institution on the security of the property of the Institution, or otherwise at their discretion.

32. No act done by the Council, whether *ultra vires* or not, which shall receive the express or implied sanction of the Members and Associate Members in General Meeting, shall be afterwards impeached by any member of the Institution on any ground whatsoever, but shall be deemed to be an act of the Institution.

NOTICES.

33. A notice may be served by the Council upon any Member, Associate Member, Graduate, Associate, or Honorary Life Member, either personally or by sending it through the post in a prepaid letter addressed to him at his registered place of abode.

34. Any notice, if served by post, shall be deemed to have been served at the time when the letter containing the same would be delivered in the ordinary course of the post; and in proving such service it shall be sufficient to prove that the letter containing the notice was properly addressed and put into the post office.

35. No Member, Associate Member, Graduate, Associate, or Honorary Life Member, not having a registered address within the United Kingdom, shall be entitled to any notice; and all proceedings may be had and taken without notice to such member, in the same manner as if he had had due notice.

By-laws.

(*Last Revision, February* 1894.)

MEMBERSHIP.

1. Candidates for admission as Members must be persons not under twenty-five years of age, who, having occupied during a sufficient period a responsible position in connection with the practice or science of Engineering, may be considered by the Council to be qualified for election.

2. Candidates for admission as Associate Members must be persons not under twenty-five years of age, who, being engaged in such work as is connected with the practice or science of Engineering, may be considered by the Council to be qualified for election, though not yet to occupy positions of sufficient responsibility, or otherwise not yet to be eligible, for admission as Members. They may afterwards be transferred at the discretion of the Council to the class of Members.

3. Candidates for admission as Graduates must be persons holding subordinate situations, and not under eighteen years of age. They must furnish evidence of training in the principles as well as in the practice of Engineering. Before attaining the age of twenty-six years, those elected after 1892 must apply for election as Members, Associate Members, or Associates, if they desire to remain connected with the Institution; they may not continue Graduates after attaining the age of twenty-six.

4. Candidates for admission as Associates must be persons not under twenty-five years of age, who from their scientific attainments or position in society may be considered eligible by the Council. They may afterwards be transferred at the discretion of the Council to the class of Associate Members or of Members.

5. The Council shall have the power to nominate as Honorary Life Members persons of eminent scientific acquirements, who in their opinion are eligible for that position.

6. The Members, Associate Members, Graduates, Associates, and Honorary Life Members shall have notice of and the privilege to attend all Meetings; but Members and Associate Members only shall be entitled to vote thereat.

7. The abbreviated distinctive Titles for indicating the connection with the Institution of Members, Associate Members, Graduates, Associates, or Honorary Life Members thereof, shall be the following:—for Members, M. I. Mech. E.; for Associate Members, A. M. I. Mech. E.; for Graduates, G. I. Mech. E.; for Associates, A. I. Mech. E.; for Honorary Life Members, Hon. M. I. Mech. E.

8. Subject to such regulations as the Council may from time to time prescribe, any Member, Associate Member, or Associate may upon application to the Secretary obtain a Certificate of his membership or other connection with the Institution. Every such certificate shall remain the property of, and shall on demand be returned to, the Institution.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. Each Member shall pay an Annual Subscription of £3, and on election an Entrance Fee of £2.

10. Each Associate Member shall pay an Annual Subscription of £2 10*s*., and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Members, he shall pay on transference 10*s*. additional subscription for the current year, and £1 additional entrance fee.

11. Each Graduate shall pay an Annual Subscription of £1 10*s*., but no Entrance Fee. Any Graduate elected prior to 1893, if transferred by the Council to the class of Associate Members, shall pay on transference £1 additional subscription for the current year, but no additional entrance fee; if transferred direct to the class of Members, he shall pay on transference £1 10*s*. additional subscription for the current year, and £1 additional entrance fee.

12. Each Associate shall pay an Annual Subscription of £2 10*s*., and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Associate Members, he shall pay on transference no additional subscription or entrance fee. If transferred direct to the class of Members, he shall pay on transference 10*s*. additional subscription for the current year, and £1 additional entrance fee; except Associates elected prior to 1893, who shall pay no additional entrance fee on transference.

13. All subscriptions shall be payable in advance, and shall become due on the 1st day of January in each year; and the first subscription of Members, Associate Members, Graduates, and Associates, shall date from the 1st day of January in the year of their election.

14. In the case of Members, Associate Members, Graduates, or Associates, elected in the last three months of any year, the first subscription shall cover both the year of election and the succeeding year.

15. Any Member, Associate Member, or Associate, whose subscription is not in arrear, may at any time compound for his subscription for the current and all future years by the payment of Fifty Pounds, if paid in any one of the first five years of his membership. If paid subsequently, the sum of Fifty Pounds shall be reduced by One Pound per annum for every year of membership after five years. All compositions shall be deemed to be capital moneys of the Institution.

16. The Council may at their discretion reduce or remit the annual subscription, or the arrears of annual subscription, of any Member or Associate Member who shall have been a subscribing member of the Institution for twenty years, and shall have become unable to continue the annual subscription provided by these By-laws.

17. No Proceedings or Ballot Lists or Certificates shall be sent to Members, Associate Members, Graduates, or Associates, who are in

arrear with their subscriptions more than twelve months, and whose subscriptions have not been remitted by the Council as hereinbefore provided.

ELECTION OF MEMBERS, ASSOCIATE MEMBERS, GRADUATES, AND ASSOCIATES.

18. A recommendation for admission according to Form A or B in the Appendix shall be forwarded to the Secretary, and by him be laid before the next Meeting of the Council. The recommendation must be signed by not less than five Members or Associate Members if the application be for admission as a Member or Associate Member or Associate, and by three Members or Associate Members if it be for a Graduate.

19. All elections shall take place by ballot, four-fifths of the votes given being necessary for election.

20. All applications for admission shall be communicated by the Secretary to the Council for their approval previous to being inserted in the ballot list for election, and the approved ballot list shall be signed by the President and forwarded to the Members and Associate Members. The name of any Candidate approved by the Council for admission as an Associate Member or an Associate shall not be inserted in the ballot list until he has signed the Form C in the Appendix. The ballot list shall specify the name, occupation, and address of the Candidates, and also by whom proposed and seconded. The lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

21. The Elections shall take place at the General Meetings only.

22. When the proposed Candidate is elected, the Secretary shall give him notice thereof according to Form D; but his name shall not be added to the register of the Institution until he shall have paid his Entrance Fee and first Annual Subscription, and signed the Form E in the Appendix.

23. In case of non-election, no mention thereof shall be made in the Minutes, nor any notice given to the unsuccessful Candidate.

24. An Associate Member desirous of being transferred to the class of Members, or an Associate to the class of Associate Members or of Members, shall forward to the Secretary a recommendation according to Form F in the Appendix, signed by not less than five Members or Associate Members, which shall be laid before the next meeting of Council for their approval. On their approval being given, the Secretary shall notify the same to the Candidate according to Form G; but his name shall not be added to the list of Members or Associate Members until he shall have signed the Form H, and shall have paid the additional entrance fee (if any), and the additional subscription (if any) for the current year.

ELECTION OF PRESIDENT, VICE-PRESIDENTS, AND MEMBERS OF COUNCIL.

25. Candidates shall be put in nomination at the General Meeting preceding the Annual General Meeting, when the Council are to present a list of their retiring Members who offer themselves for re-election; any Member or Associate Member shall then be entitled to add to the list of Candidates. The ballot list of the proposed names shall be forwarded to the Members and Associate Members. The ballot lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

APPOINTMENT AND DUTIES OF OFFICERS.

26. The Treasurer shall be a Banker, and shall hold the uninvested funds of the Institution, except the moneys in the hands of the Secretary for current expenses. He shall be appointed by the Members and Associate Members at a General or Special Meeting, and shall hold office at the pleasure of the Council.

27. The Secretary of the Institution shall be appointed, as and when a vacancy occurs, by the Members and Associate Members at a General or Special Meeting, and shall be removable by the Council upon six months' notice from any day. The Secretary shall give the same notice. The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or profession.

28. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all meetings of the Institution, and of the Council, and of Committees; to take minutes of the proceedings of such meetings; to read the minutes of the preceding meetings, and all communications that he may be ordered to read; to superintend the publication of such papers as the Council may direct; to have the charge of the library; to direct the collection of the subscriptions, and the preparation of the account of expenditure of the funds; and to present all accounts to the Council for inspection and approval. He shall also engage (subject to the approval of the Council) and be responsible for all persons employed under him, and set them their portions of work and duties. He shall conduct the ordinary business of the Institution, in accordance with the Articles and By-laws and the directions of the President and Council; and shall refer to the President in any matters of difficulty or importance, requiring immediate decision.

MISCELLANEOUS.

29. All Papers shall be submitted to the Council for approval, and after their approval shall be read by the Secretary at the General Meetings, or by the Author with the consent of the Council; or, if so directed by the Council, shall be printed in the Proceedings without having been read at a General Meeting.

30. All books, drawings, communications, &c., shall be accessible to the members of the Institution at all reasonable times.

31. All communications to the Meetings shall be the property of the Institution, and be published only by the authority of the Council.

32. None of the property of the Institution—books, drawings, &c.—shall be taken out of the premises of the Institution without the consent of the Council.

33. All donations to the Institution shall be enumerated in the Annual Report of the Council presented to the Annual General Meeting.

34. The General Meetings shall be conducted as far as practicable in the following order:—

1st. The Chair to be taken at such hour as the Council may direct from time to time.

2nd. The Minutes of the previous Meeting to be read by the Secretary, and, after being approved as correct, to be signed by the Chairman.

3rd. The Ballot Lists, previously opened by the Council, to be presented to the Meeting, and the new Members, Associate Members, Graduates, and Associates elected to be announced.

4th. Papers approved by the Council to be read by the Secretary, or by the Author with the consent of the Council.

35. Each Member or Associate Member shall have the privilege of introducing one friend to any of the Meetings; but, during such portion of any meeting as may be devoted to any business connected with the management of the Institution, visitors shall be requested by the Chairman to withdraw, if any Member or Associate Member asks that this shall be done.

36. Every Member, Associate Member, Graduate, Associate, or Visitor, shall write his name and residence in a book to be kept for the purpose, on entering each Meeting.

37. The President shall ex officio be member of all Committees of Council.

38. Seven clear days' notice at least shall be given of every meeting of the Council. Such notice shall specify generally the business to be transacted by the meeting. No business involving the expenditure of the funds of the Institution (except by way of payment of current salaries and accounts) shall be transacted at any Council meeting unless specified in the notice convening the meeting.

39. The Council shall present the yearly accounts to the Annual General Meeting, after being audited by a professional accountant, who shall be appointed annually by the Members and Associate Members at a General or a Special Meeting, at a remuneration to be then fixed by the Members and Associate Members.

40. Any member wishing to have a copy of the Papers sent to him for consideration beforehand can do so by sending in his name once in each year to the Secretary; and a copy of all Papers shall then be forwarded to him as early as possible prior to the date of the Meeting at which they are intended to be read.

41. At any Meeting of the Institution any member shall be at liberty to re-open the discussion upon any Paper which has been read or discussed at the preceding Meeting; provided that he signifies his intention to the Secretary at least one month previously to the Meeting, and that the Council decide to include it in the notice of the Meeting as part of the business to be transacted.

APPENDIX.

FORM A.

Mr. being years of age, and desirous of admission into the Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our personal knowledge, and the three other signers from trustworthy information, propose and recommend him as a proper person to belong to the Institution.

Witness our hands, this day of

Members or Associate Members.

FORM B.

Mr. born on being desirous of admission into the Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our personal knowledge, and the other signer or signers from trustworthy information, propose and recommend him as a proper person to become a Graduate thereof.

Witness our hands, this day of

Members or Associate Members.

FORM C.

If elected an of the Institution of Mechanical Engineers, I, the undersigned, do hereby engage to ratify my election by signing the form of agreement and paying the entrance fee and annual subscription in conformity with the By-laws.

Witness my hand, this day of

FORM D.

Sir,—I have to inform you that on the you were elected a of the Institution of Mechanical Engineers. For the ratification of your election in conformity with the rules, it is requisite that the enclosed form be returned to me with your signature, and that your Entrance Fee and first Annual Subscription be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the election will become void.

I am, Sir, Your obedient servant,

Secretary.

FORM E.

I, the undersigned, being elected a of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they are now formed or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

FORM F.

Mr. being years of age, and desirous of being transferred into the class of of the Institution of Mechanical Engineers, we, the undersigned, from our personal knowledge recommend him as a proper person to be so transferred by the Council.

Witness our hands, this day of

Members or Associate Members.

FORM G.

Sir,—I have to inform you that the Council have approved of your being transferred to the class of of the Institution of Mechanical Engineers. For the ratification of your transference in conformity with the rules, it is requisite that the enclosed form be returned to me with your signature, and that your additional Entrance Fee and additional Annual Subscription for the current year be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the transference will become void.

I am, Sir, Your obedient servant,

Secretary.

FORM H.

I, the undersigned, having been transferred to the class of of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they now exist, or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

Institution of Mechanical Engineers.

PROCEEDINGS.

January 1896.

The Forty-Ninth Annual General Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Thursday, 30th January 1896, at Half-past Seven o'clock p.m.; Professor Alexander B. W. Kennedy, LL.D., F.R.S., Retiring President, in the chair, succeeded by E. Windsor Richards, Esq., President elected at the Meeting.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following thirty-two candidates were found to be duly elected:—

MEMBERS.

Barker, Matthew Wilson,	Johannesburg.
Bradney, Walter,	London.
Conaty, George,	Birmingham.
Dorman, William Sansom,	Gloucester.
Eborall, Cornelius Willes,	Jamalpur.
Ellis, William Frederick Wood,	Bombay.
Glasgow, Arthur Graham,	London.
Hodges, Marcus Henry,	Exeter.
Holmes, Percy Frederick,	Huddersfield.
Howarth, Alfred Montgomery,	Sydney.
Jenkinson, Thomas,	St. Helen's.

MAIN, WILLIAM HENDERSON, . .	Bombay.
MARSH, DOUGLAS EARLE, . . .	Swindon.
WOOD, WALTER CHAPMAN, . . .	Bombay.

ASSOCIATE MEMBERS.

BARTON, ANDREW, ...	London.
CONRADI, JULIUS SAMUEL, . . .	London.
DOSSOR, HERBERT, ...	London.
HALL, BENJAMIN JAMES, . . .	London.
MANSFIELD, ALFRED, ...	Madras.
NICHOLLS, PERCY, ...	Salford.
SAMUEL, BLELOCK LEE, . . .	Glasgow.
STEWART, CHARLES NIGEL, . . .	London.
TRAFFORD, ALFRED, ...	Birmingham.
UMNEY, HERBERT WILLIAMS, . . .	Bath.
WISEMAN, ALFRED, ...	Birmingham.

ASSOCIATES.

DEVINE, WILLIAM HENRY, . . .	Nagasaki.
KITTO, WILLIAM HENRY, . . .	London.
TAYLOR, JOSEPH HENRY, . . .	London.

GRADUATES.

BARBOSA, AGENOR, ...	Paris.
DAVSON, STEPHEN FREDERICK, . .	London.
GODDARD, WILLIAM HERBERT, . .	Croydon.
THOM, FRANK, ...	Blackburn.

The following Annual Report of the Council was then read:—

ANNUAL REPORT OF THE COUNCIL.

1896.

On this occasion of the Forty-Ninth Annual General Meeting of the Institution, the Council have the pleasure of presenting to the Members the following Report of the business and progress of the Institution during the past year.

At the end of last year the number of names in all classes on the roll of the Institution was 2,271, as compared with 2,222 at the end of the previous year, showing a net gain of 49. During 1895 there were added to the register 158 names; against which the loss by decease was 25, and by resignation or removal 84.

During 1895 the following distinctions have been conferred by the Queen upon Members of this Institution. Dr. William Anderson, C.B., Past-President, Director-General of Ordnance Factories, has been made a Companion of the Bath. The Right Honourable Sir Bernhard Samuelson, Bart., has been appointed a member of Her Majesty's Privy Council. Sir William H. White, K.C.B., Member of Council, Assistant Controller and Director of Naval Construction, has been created Knight Commander of the Bath. To each gentleman the Council have had the pleasure of offering their congratulations on behalf of the Institution.

The following eleven Transferences have been made by the Council in 1895:—

To the class of Members.

Parkinson, Hudson Clough,	Associate Member	Bristol.
Ramsbottom, John Goodfellow,	Associate Member	Manchester.
Edwards, Walter Cleeve, .	. Graduate	. New Zealand.

To the class of Associate Members.

Burne, Edward Lancaster, .	. Graduate	. Guildford.
Douglass, Alfred Edwards,	. do.	. Birmingham.
Edwards, Herbert Francis,	. do.	. Cardiff.

PRICE-WILLIAMS, JOHN MORGAN,	Graduate	London.
SMITH, JOSEPH PHILIP GRACE,	do.	London.
SNELL, JOHN FRANCIS CLEVERTON,	do.	London.
TABOR, EDWARD HENRY,	do.	London.
WRIGHT, HOWARD THEOPHILUS,	do.	London.

The following twenty-seven Deceases of Members of the Institution have occurred during the past year :—

ARMITAGE, WILLIAM JAMES,	Leeds.
ARMSTRONG, WILLIAM HENRY (Associate Member),	Calcutta.
BAILEY, WILLIAM,	London.
BREBNER, SAMUEL GORDON,	Poona.
BURNET, LINDSAY,	Glasgow.
COXHEAD, FREDERICK CARLEY,	London.
DICKINSON, RICHARD ELIHU,	Bradford.
DICKSON, GEORGE MANNERS,	Calcutta.
ELWELL, THOMAS,	Paris.
FLETCHER, HERBERT,	Bolton.
GÖTZ, CARL JOHANN WILHELM (Associate),	Manchester.
GREENER, JOHN HENRY,	London.
GUY, CHARLES WILLIAMS (deceased 1893),	Java.
HARLAND, Sir EDWARD JAMES, Bart., M.P.,	Belfast.
JAMES, CHRISTOPHER,	Bristol.
JAMIESON, JAMES LINDSAY AULDJO- (Graduate),	Newcastle-on-Tyne.
MITCHELL, CHARLES,	Newcastle-on-Tyne.
NAPIER, JAMES MURDOCH,	London.
PAGET, ARTHUR,	Loughborough.
PINEL, CHARLES LOUIS,	Rouen.
REYNOLDS, EDWARD,	Sheffield.
SCORGIE, Professor JAMES,	Poona.
STIRLING, PATRICK,	Doncaster.
TURNER, JOSHUA ALFRED ALEXANDER,	Poona.
TWEDDELL, RALPH HART,	London.
WILD, JOHN,	Oldham.
WOOD, ROBERT HENRY,	Leeds.

Of these Mr. Paget was a Member of the Institution from 1868, a Member of Council from 1878, and a Vice-President from 1887 to 1891, after which he was debarred by illness from continuing the active interest he had previously taken in the management of the Institution. Mr. Tweddell had joined the Institution in 1867, and

was a Member of Council from 1883 to 1885; just prior to his sudden death he had been nominated by the Council for election again at the present meeting.

The following twenty-eight gentlemen have ceased to be Members of the Institution during the past year:—

Arnold, David Nelson,	Southsea.
Beckwith, George Charles,	Swansea.
Bridie, Ronald Hope,	London.
Brown, Arthur Selwyn (Graduate),	Sydney.
Browne, Frederick John,	London.
Coley, Henry,	London.
Collen, Robert Henry,	Northfleet.
Copeland, Charles John,	Liverpool.
Errington, William,	Melbourne.
Gore, Arthur Saunders,	Birmingham.
Harrison, Abraham Wyke,	Abergavenny.
Hart, Norman,	London.
Lambourn, Thomas William,	Bildeston.
Macleod, Arthur William,	Burmah.
McGregor, Josiah,	London.
McKay, John,	Newcastle-on-Tyne.
Miles, William Henry (Associate),	Johannesburg.
Monie, Hugh, Jun. (Associate),	Bombay.
Moor, William (Graduate),	Hartlepool.
Nordenfelt, Thorsten,	Paris.
Penn, George Williams,	Cardiff.
Richards, George,	London.
Rochfort, Bertram (Associate),	Rio de Janeiro.
Sellers, George,	Sheffield.
Soulsby, James Charlton,	Cardiff.
Stumore, Frederick (Associate),	London.
Wailes, John William,	Gateshead.
Wheildon, John Henry,	London.

In addition to these there have been fifty-five Resignations of membership.

The Accounts for the year ending 31 December 1895 are now submitted to the Members (*see* pages 12–15), after having been passed by the Finance Committee, and certified by Mr. Robert A.

McLean, chartered accountant, the auditor appointed by the Members at the last Annual General Meeting. The receipts during the year were £7,274 19*s.* 4*d.*, while the expenditure, actual and estimated, was £5,588 0*s.* 7*d.*, leaving a balance of receipts over expenditure of £1,686 18*s.* 9*d.* The financial position of the Institution at the end of the year is shown by the balance sheet: the total investments and other assets amount to £42,652 8*s.* 6*d.*; and allowing £600 for accounts owing but not yet rendered, the capital of the Institution amounts to £42,052 8*s.* 6*d.*, of which the greater part, as seen from the balance sheet, is invested in Railway Debenture Stocks, registered in the name of the Institution. The certificates of the whole of the securities have been duly audited by the Finance Committee and the auditor.

At the last Annual General Meeting the desirability of obtaining a House for the Institution was again urged upon the Council, and the President had the pleasure of announcing that a Committee of the Council had already been appointed to look into this subject. Subsequently the President was able further to announce at the Summer Meeting in Glasgow that the Council had agreed to purchase half of a vacant site at Storey's Gate, Westminster, fronting St. James' Park. The purchase has now been completed of this site for a period of seventy-nine years from Midsummer last, the owners of the property being the Ecclesiastical Commissioners. Already the heavy work of excavating and draining, shoring, concreting, and underpinning an adjoining building, has been carried out; and contracts are being prepared for the building to be erected from plans approved by the Council. Next year therefore it is hoped the Members may be in possession of a House of their own, containing a Meeting Room about sixty feet by forty, a Library of not less area, a capacious Reading and Smoking Room, a Council Room, a commodious tea-room, and the necessary accommodation for offices, storage, and housekeeper.

Since the last Annual General Meeting the Third Report of the Research Committee on the Value of the Steam-Jacket, under the

chairmanship of Mr. Henry Davey, has been published; and during the past year apparatus has been specially constructed with a view to carrying out, as then announced, a series of laboratory experiments bearing upon steam-cylinder condensation. The experiments are now being carried out at University College, London, where the apparatus has been fixed.

The Third Report of Professor Roberts-Austen to the Alloys Research Committee, of which Dr. William Anderson is the chairman, was read and discussed at the spring meeting of the Institution, and was accompanied by appendices on Best Selected Copper by Mr. Allan Gibb, and on Copper-Tin Alloys by Mr. Alfred Stansfield. The continuation of this Research is still in progress by Professor Roberts-Austen.

The Lille Experiments upon the use of Ropes and Belts for the Transmission of Power were discussed at the autumn meeting, at which Professor Capper, who had attended the trials on behalf of this Institution, presented a translation of the Report of the Committee, accompanied by an independent account of his own observations upon the trials. Although the anticipations which had been entertained beforehand went somewhat beyond the results realised from the actual conduct of the experiments, the free discussion of the subject had none the less the advantage of eliciting practical information and expressions of opinion, of which the Members might not otherwise have had the benefit. Moreover it is hoped that the opportunity so courteously offered to the Institution of appointing a representative to attend these trials may serve as a precedent for similar co-operation upon future occasions and in other subjects of experimental research.

Already the Council have appointed an additional Committee, under the chairmanship of the President, to take charge of a Research respecting the Temperatures and Pressures and other conditions pertaining to the working of Gas Engines. They have also under consideration the desirability of aiding in further Steam-Engine Research.

Respecting the Willans Memorial, of which the particulars were announced in their last Annual Report, the Council now direct

attention to the statement of account presented herewith for the past year (pages 16–17), showing the amount of the fund, and of the income received therefrom; the latter amounts in the present statement to only half a year's income, because the date at which the fund was invested was not early enough to secure the first quarter's dividend, and the fourth quarter's is payable on 5th January of the present year. The Council of this Institution, jointly with the Council of the Institution of Electrical Engineers, are the trustees of the fund, which was raised in memory of the late Mr. P. W. Willans for the purpose of awarding triennially or at longer intervals a premium for the best original paper on such a general subject as the utilization or transformation of energy, treated especially from the point of view of efficiency or economy. The first award will be made in December of next year, 1897, by the Institution of Electrical Engineers.

The repeal of existing statutes, so far as they operate to prevent Mechanical Locomotion upon Common Roads, apart from traction engines, formed the subject of a memorial to the Right Honourable Henry Chaplin, M.P., President of the Local Government Board, which was signed by many of the Members attending the autumn meeting of the Institution. Should the appeal prove successful, the Council are sanguine enough to anticipate with confidence the speedy development of a branch of mechanical engineering, which may even call forth an amount of enterprise exceeding anything that has yet arisen in connection with the remarkably rapid growth of the cycle manufacture.

The Library of the Institution has received by presentation and exchange during the past year the additions enumerated in pages 18–26, for which the Council here record their thanks to the several Donors. Members who have published works valuable for reference, or original pamphlets on engineering subjects, or records of experiments, of which they could present copies, are reminded that such contributions to the Library are acceptable for permanent preservation.

The General Meetings in 1895 were the Annual General Meeting and the Spring Meeting, both held in London; the Summer Meeting in Glasgow; and the Autumn Meeting in London. Altogether eight sittings were occupied in the reading and discussion of twelve of the following Papers, which are published in the Proceedings:—

The Determination of the Dryness of Steam; by Professor W. Cawthorne Unwin, F.R.S.

Experiments on a Vertical Single-cylinder Steam-Engine, with and without Steam in the Jackets, Condensing and Non-condensing, Double and Single-acting, at different Expansions, with Saturated and Superheated steam; by Mr. Bryan Donkin.

Governing of Steam Engines by Throttling and by Variable Expansion; by Capt. H. Riall Sankey.

Third Report to the Alloys Research Committee; by Professor W. C. Roberts-Austen, C.B., F.R.S.

Appendix on the Elimination of Impurities during the process of making "Best Selected" Copper; by Mr. Allan Gibb, A.R.S.M.

Appendix on the Pyrometric Examination of the Alloys of Copper and Tin; by Mr. Alfred Stansfield, A.R.S.M.

Locomotive Building in Japan; by Mr. Richard F. Trevithick.

Hydraulic Stoking Machinery and Labour-Saving Appliances in modern Gas Works; by Mr. Andrew S. Biggart.

Notes on Hydraulic Power Supply in Towns: Glasgow, Manchester, Buenos Aires, &c.; by Mr. Edward B. Ellington.

Recent Engineering Improvements of the Clyde Navigation; by Mr. James Deas.

Notes on modern Steel-Works Machinery; by Mr. James Riley.

The Electric Lighting of Edinburgh; by Mr. Henry R. J. Burstall.

Report on the Lille Experiments upon the Comparative Efficiency of Ropes and Belts for the Transmission of Power; translated by Professor David S. Capper.

Observations on the Lille Experiments upon the Comparative Efficiency of Ropes and Belts for the Transmission of Power; by Professor David S. Capper.

Abstract of Report on the results of preliminary tests of the Strength of Copper; by Professor A. Martens. Translated and abstracted by Mr. C. H. Moberly.

The attendances during 1895 were as follows:—at the Annual General Meeting 100 Members and 111 Visitors; at the Spring

Meeting 73 Members and 55 Visitors; at the Summer Meeting 298 Members and 129 Visitors; and at the Autumn Meeting 75 Members and 68 Visitors.

The Summer Meeting was held in Glasgow, after an interval of sixteen years since the last meeting took place in that City in 1879. It was made the occasion for Papers of wide engineering interest, dealing with local enterprises which there was at the same time the opportunity of inspecting:—namely the Gas Works, with the most recent hydraulic machinery for charging and drawing the retorts; the Hydraulic Power Supply just brought into operation; the Clyde Navigation, and the works still in progress for Cessnock Dock; and also the modern Steel-Works Machinery in use at the works of the Glasgow Iron and Steel Company at Wishaw. The visits to these several Works, and to the many other engineering, shipbuilding, and manufacturing establishments opened to the inspection of the Members, were arranged in connection with the several proprietors and authorities by an Executive Committee under the chairmanship of Sir Renny Watson, and by sub-committees of which Sir William Arrol, M.P., and Mr. Stephen Alley were chairmen. The Honourable the Lord Provost, Sir James Bell, Bart., and Lady Bell, signalised the Meeting by inviting the Members to a Conversazione in the Municipal Buildings; and a concluding day's Excursion upon the Firth of Clyde was provided by the kindness of the Executive Committee.

The details of the attractive programme drawn up by the Committee were undertaken and admirably carried out by Professor Archibald Barr, as Honorary Secretary; and as an expression of the high appreciation, shared with themselves by all who attended the Glasgow Meeting, of the value of his kind exertions for their gratification, the Council have presented him with a bronze statuette "Mignon," bearing a suitable inscription commemorating his aid.

The Council have the pleasure of announcing that they have decided upon holding the Summer Meeting in the present year in Belfast, in response to representations received from local Members

in favour of this decision. On the occasion of the Dublin Meeting in 1888, whence too short a visit was paid to Belfast, it was felt that a Summer Meeting in Belfast would be highly desirable at an early opportunity; and the prospect is now welcome of realising the wish then originated and since cherished.

In accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of the Council, retire from office this day. The result of the ballot for the election of the Council for the present year will be announced to the Meeting.]

Dr. ACCOUNT OF EXPENDITURE AND RECEIPTS

Expenditure.	£	s.	d.	£	s.	d.
To Printing and Engraving Proceedings of 1895 . .	1,133	19	2			
Less Authors' Copies of Papers, repaid	26	5	0	1,107	14	2
,, Stationery and General Printing				199	9	7
,, Binding				29	3	0
,, Rent of Offices				710	0	0
,, Salaries and Wages				1,936	1	0
,, Coal, Firewood, and Lighting				43	14	3
,, Fittings and Repairs				36	11	6
,, Postages, Telegrams, and Telephone				294	14	10
,, Insurance				7	0	6
,, Petty Expenses				32	7	10
,, Meeting Expenses—						
Printing	176	7	8			
Reporting	56	2	3			
Diagrams, Screen, &c.	191	18	4			
Travelling and Incidental Expenses	301	19	8	726	7	11
,, Dinner Guests				52	1	11
,, Research				404	18	6
,, Books purchased				6	14	1
,, Willans Premium Fund				1	1	6
				5,588	0	7
Accounts owing, not yet rendered, say	600	0	0			
Less Reserve in previous year for accounts since paid	600	0	0	0	0	0
Balance, being excess of Receipts over Expenditure, carried down—				1,686	18	9
				£7,274	19	4

	£	s.	d.	£	s.	d.
To Investment—						
£1,200 *Great Western Railway* 4% *Debenture Stock* . . .				1,782	4	0
To House for Institution—						
Expended on Building to date	1,352	16	4			
Ground Rent during construction	422	12	1	1,775	8	5
Cash Balance 31st December 1895				2,623	0	1
				£6,180	12	6

FOR THE YEAR ENDING 31ST DECEMBER 1895. *Cr.*

Receipts.	£ s. d.	£ s. d.
By Entrance Fees—		
70 *New Members at £2*	140 0 0	
55 *New Associate Members at £1*	55 0 0	
4 *New Associates at £1*	4 0 0	
2 *Associate Members transferred to Members at £1*	2 0 0	
1 *Graduate transferred to Member at £1*	1 0 0	202 0 0
,, Subscriptions for 1895—		
1635 *Members at £3*	4,905 0 0	
117 *Associate Members at £2 10s.*	292 10 0	
59 *Associates at £2 10s.*	147 10 0	
148 *Graduates at £1 10s.*	222 0 0	
2 *Associate Members transferred to Members at 10s.*	1 0 0	
1 *Graduate transferred to Member at £1 10s.*	1 10 0	
8 *Graduates transferred to Associate Members at £1*	8 0 0	5,577 10 0
,, Subscriptions in arrear—		
90 *Members at £3*	270 0 0	
5 *Associate Members at £2 10s.*	12 10 0	
1 *Associate at £2 10s.*	2 10 0	
2 *Graduates at £2*	4 0 0	
10 *Graduates at £1 10s.*	15 0 0	304 0 0
,, Subscriptions in advance—		
24 *Members at £3*	72 0 0	
6 *Associate Members at £2 10s.*	15 0 0	
2 *Associates at £2 10s.*	5 0 0	
2 *Graduates at £1 10s.*	3 0 0	95 0 0
,, Interest—		
From Investments	890 9 4	
From Whitworth Bequest	133 16 8	
From Bank	13 1 10	1,037 7 10
,, Reports of Proceedings— *Extra Copies sold*		59 1 6
		£7,274 19 4

	£ s. d.
By Balance brought down	1,686 18 9
By Life Compositions, 2 Members	35 0 0
By Sale of Investments	1,765 18 0
Cash Balance 31st December 1894	2,692 15 9
	£6,180 12 6

Dr. BALANCE SHEET

	£	s.	d.
To Sundry Creditors—			
Accounts owing, not yet rendered, say	600	0	0
Capital of the Institution at this date (exclusive of back numbers of Proceedings, which cost £5,000)	42,052	8	6
	£42,652	8	6

Signed by the following members of the Finance Committee:—

ALEXANDER B. W. KENNEDY,
DOUGLAS GALTON,
BRYAN DONKIN,
JOHN HOPKINSON,
JOHN G. MAIR-RUMLEY,
WILLIAM H. MAW.

AS AT 31ST DECEMBER 1895. *Cr.*

		£ s. d.	£ s. d.	£ s. d.
By Cash—*In Union Bank, on Deposit*			1,695 18 0	
" " " *on Current account* . .			427 2 1	
In London Joint Stock Bank		312 3 4		
In hand { *expended since closing accounts* }		187 16 8	500 0 0	2,623 0 1
" Investments—(*cost* £27,340 9*s*. 9*d*.)				
£ 2,200 *North Eastern Railway*	4% *Debenture Stock*			
3,000 *Great Western* "	" " "			
2,244 *Great Eastern* "	" " "			
2,755 *Metropolitan* "	" " "			
2,325 " "	3½% " "			
1,000 *Aire and Calder Navigation*	" " "			
4,237 *London and North Western Ry.*	3% " "			
3,288 *Midland Railway*	" " "			
2,450 *Taff Vale* "	" " "			
4,053 *India* 3% *Stock*				
One hundred and five £10 shares Sir J. Whitworth and Co., Ld.				
The Market Value of these investments at 31st Dec. 1895 was about . .				36,271 0 0
" Subscriptions in Arrear, probable value				300 0 0
" Office Furniture and Fittings				343 0 0
" Library				1,240 0 0
" Drawings, Engravings, Models, Specimens, and Sculpture .				100 0 0
" Proceedings, back numbers, cost £5,000				
" House for Institution, expenditure to date				1,775 8 5
				£42,652 8 6

Audited and Certified by

ROBERT A. McLEAN, F.C.A.,
Auditor,
1 Queen Victoria Street, London, E.C.

Dr. WILLANS

	£	s.	d.
To Investment £159 8*s*. 5*d*. of India 3% Stock	165	5	0
	£165	5	0
To Interest received, half year	2	7	8
	£2	7	8

DECLARATION OF TRUST OF THE WILLANS PREMIUM FUND.

To all to whom these presents shall come The Institution of Mechanical Engineers and The Institution of Electrical Engineers send greeting. Whereas a Fund has been subscribed by the friends of the late PETER WILLIAM WILLANS, of Thames Ditton, for the purpose of commemorating his name and the services which he rendered to Engineering and Electrical science; and at the request of the subscribers to the said fund the above-named Institutions have agreed to act as joint Trustees thereof, and the sum of One hundred and sixty-five pounds has accordingly been paid to the said Institutions: now these presents witness that the said Institutions do hereby declare the Trusts upon which they hold the said fund to be as follows:—

1. To invest the said fund upon such securities as trustees are by law authorised to hold, and in such names as the Councils of the two Institutions shall from time to time direct.

2. To apply the proceeds of the said investment as and when received, after payment of any expenses incidental to the administration of the trust, to the Premium hereinafter described, to be known as "the Willans Premium."

3. The Willans Premium shall be awarded alternately by the Council of each of the above-mentioned Institutions; and first by the Institution of Electrical Engineers in December 1897.

4. The Council of the awarding Institution in each alternate period shall award the Willans Premium for the best original paper communicated to their Institution, dealing with such a general

PREMIUM FUND. *Cr.*

	£	s.	d.
By Fund subscribed	164	3	6
„ Institution of Mechanical Engineers	1	1	6
	£165	5	0
By Held in trust by Institution of Mechanical Engineers	2	7	8
Audited, certified, and signed by the names on pages 14–15.	£2	7	8

subject as the utilisation or transformation of energy, treated especially from the point of view of efficiency or economy: provided that the Premium shall not be awarded unless a paper of sufficient merit in the judgment of the awarding Council shall have been so communicated since the preceding award of that Council.

5. The Premium shall be awarded triennially in and after December 1897, unless otherwise determined by resolution of the respective Councils of the two Institutions.

6. The Premium may be awarded either in money or books or medal, or in any other form which in the instance of any individual award the awarding Council may then determine.

7. In case of no award at the end of any triennial period, the premium available for that award shall be added to the capital of the fund.

In witness whereof the Institution of Mechanical Engineers have hereunto affixed their common seal, and the President and Secretary of the Institution of Electrical Engineers have hereunto set their hands, this sixteenth day of January 1895.

The Seal of the Institution of Mechanical Engineers was impressed by the President in the presence of Alfred Bache, Secretary; and the document was signed as follows:—

ALEXANDER B. W. KENNEDY,
President of the Institution of Mechanical Engineers.

R. E. CROMPTON,
President of the Institution of Electrical Engineers.

F. H. Webb, Secretary of the Institution of Electrical Engineers.

LIST OF DONATIONS TO LIBRARY.

Text-book on Gas, Oil, and Air Engines, by Bryan Donkin; from the author.

The Water Meter, its difficulties, types, and applications, by Walter G. Kent; from the author.

Bores and Loads for Sporting Guns for British Game Shooting, by W. A. Adams; from the author.

Twenty-six years' Reminiscences of Scotch Grouse Moors, by W. A. Adams; from the author.

Appliances and Apparatus for the Prevention of Accidents in Factories; from the Society for the Prevention of Accidents in Factories, Mulhouse.

The following from the author, Mr. Henry Webb:—Prompt Aid to the Injured; With the Iron and Steel Institute to America; Manufacture of Iron; Steel and its Manufacture.

Practical Treatise on Gas Light, by Frederick Accum; from Mr. Bryan Donkin.

Steam Power and Mill Work, by G. W. Sutcliffe; from the publishers.

Motive Powers and their practical selection, by R. Bolton; from the publishers.

The Steam Jacket, by W. Fletcher; from the publishers.

The following from the author, Mr. Jeremiah Head:—American Rail and Tram ways; Manufacture of cheap Pig Iron, &c., in the southern states of North America.

The following from Mr. James Robert Mosse:—Canadian Pacific Railway Report 1880; Annual Report of the Railroad Commissioners of the State of New York, Part I., 1885; Civil Engineer and Architect's Journal, 1840–42, 1848, 1849; Permanent Way and Coal-burning Locomotive Boilers of European Railways, by Z. Colburn and A. L. Holley; Engineer and Machinist's Assistant, Text and Plates.

Photography, Artistic and Scientific, by R. Johnson and A. B. Chatwood; from Mr. A. B. Chatwood.

Engineering Contracts and Specifications, by J. B. Johnson; from the Engineering News Publishing Co.

The following from the author, Sir Guilford L. Molesworth, K.C.I.E.:—Report on Proposed Railway from Mombasa to Victoria Nyanza; Railway Construction.

Ausgeführte Heizungs- und Lüftungs-Anlagen, by David Grove; from the author.

Wirksamkeit der Dampf-mäntel bei Dampf-maschinen, by M. F. Gutermuth ; from the author.

Wolhuter Gold Mining Co., Report and Balance Sheet, October 1894; from the Company.

South African Association of Engineers and Architects, Proceedings, Vols. 1 and 2, 1892–95; from the Association.

Temperature-Entropy or Theta-Phi Chart for one pound of H_2O in British Units; from Capt. H. Riall Saukey.

Application of Electro-Motors for Power Purposes, by Thomas L. Miller; from the author.

Verbund-Lokomotiven in Nord-Amerika, by E. Brückmann; from the author.

Rede zum Geburts-feste seiner Majestät des Kaisers und Königs Wilhelm II. in der Aula der Königlichen Technischen Hoch-schule zu Berlin, 26 Januar 1895; from the Rector.

Lubricants, their use, testing, and analysis, by W. F. E. Seymour; from the author.

Report of the Hydraulic Engineer on the Water Supply of Queensland, 1894 ; from Mr. J. B. Henderson.

Étude expérimentale de la Vaporisation dans les Chaudières de Locomotives, by A. Henry ; from M. Georges Marié.

L'Or à Minas Geraes, vol. 2, part 1, by P. Ferrand; from the author.

Sixth Annual Report of the De Beers Consolidated Mines for year ending 30 June 1894; from Mr. Thomas Quentrall.

General Specifications for the construction of a Stiffened Suspension Bridge over the Hudson River at New York City, by Theodore Cooper; from the author.

List of Chinese Lighthouses, Light Vessels, Buoys, and Beacons, 1895; from the Inspector-General of Chinese Customs.

Report upon the Explosion of a Boiler at Eagle Wharf Road, London, 17 December 1894, by J. C. Chapman; from the author.

Whirling and Vibration of Shafts, by Stanley Dunkerley; from the author.

Recent developments of Coal Mining in Japan, by George Cawley; from the author.

The following from M. E. Sauvage : — Prise des éprouvettes d'essais ; Comparaison des résultats fournis par différentes éprouvettes prélevées sur une même pièce métallique; Rapport sur les Locomotives Articulées Compound à quatre cylindres de A. Mallet.

Presidential Address to the Institution of Mining and Metallurgy, by J. H. Collins ; from the author.

Artesian Water in the western interior of Queensland, by R. J. Jack; from the Government of Queensland.

Examples of high-grade Pumping Engines, by E. D. Leavitt, Jun. ; from the author.

Proceedings of the Conference on Inland Navigation, 1895; from the Federated Institution of Mining Engineers.

Inland Navigation, with special reference to the Birmingham district, by L. F. Vernon-Harcourt; from the author.

Soundings in various oceans, taken by the India-rubber, Gutta-percha, and Telegraph Works Co., 1889–94 (two pamphlets); from the company.

Bi-annual Report of the Johannesburg Sanitary Committee, Public Works Department, to 31 December 1894; from Messrs. Clowes and Sons.

Decimal Problem and its urgency, by Professor R. M. Walmsley; from Mr. K. Morven.

Report of Proceedings of the new Decimal Association, 20 November 1894; from the Association.

Water-Tube Boilers, by A. R. Edmondson; from the author.

Water-Tube Boilers, by Professor W. H. Watkinson; from the author.

The following from the Ministère des Travaux publics:—Atlas des voies navigables de la France, Canal du Centre; Commission des méthodes d'essai des Matériaux de Construction; Notes bibliographiques sur la question des essais et laboratoires d'essais des Matériaux de Construction, by R. Cordier.

Explosionen der Dampf-leitungen auf Schiffen, by H. Gwilt; from the author.

New Velocity Recorder, and its application to Anemometry and other purposes, by J. Alfred Griffiths; from the author.

The Slide-Rule and some of its applications, by Theodore Reunert; from the author.

Village Water Supplies, by Reginald E. Middleton; from the author.

Reports of the Kew Observatory Committee, 1893 and 1894; from the Committee.

Express Locomotives, by John A. F. Aspinall; from the author.

Steam-Engine Economy, with description and tests of Field's combined steam and hot-air engine, by Professor Andrew Jamieson; from the author.

Theory and Action of some automatically balanced Machinery, by W. Worby Beaumont; from the author.

Electrical Transmission and Distribution of Power; from the Electrical Co.

Engineering and Shipbuilding in the Far East, by W. C. Jack; from the Institution of Engineers and Shipbuilders, Hong Kong.

Register of the Institute of Chemistry of Great Britain and Ireland, 1895–96; from the Institute.

Catalogue of Science Library, South Kensington Museum, supplement 1895; from the Science and Art Department.

Classified Lists and Distribution Returns of Establishment, Indian Public Works Department, to 31 Dec. 1894 and 30 June 1895; from the Registrar.

Glasgow Harbour Tunnel; from the Otis Elevator Co.

The following from the Ordnance Office, Washington, United States:—Annual Report of the United States Chief of Ordnance, 1894; Notes on the Construction of Ordnance.

Tables for Degree Curve and Intersection Angles from 90° to 180°, also for Fixed Tangents from 100 ft. to 7,500 ft., by F. G. Brook-Fox; from the author.

Trials of Oil Engines at Cambridge, by Professor David S. Capper; from the author.

Strength of Canadian Douglas Fir, Red Pine, White Pine, and Spruce, by Professor Henry T. Bovey; from the author.

Engineering Works and Operations at Perim Island, by John Reney Smith; from the author.

Presidential Address to the Mechanical Science Section of the British Association, 1895, by L. F. Vernon-Harcourt; from the author.

Hungarian Patent Law of 7th July 1895; from Mr. J. G. Hardy.

Measurement of Cyclically Varying Temperature, by Frederic W. Burstall; from the author.

Considérations sur les phénomènes du Frottement dans les machines, by N. J. Raffard; from the author.

Effects of the Products of Combustion upon explosive mixtures of Coal Gas and Air, by F. Grover; from the author.

Photograph of work exhibited by the King's Norton Metal Co. at the Iron and Steel Institute Meeting, Birmingham 1895; from Mr. T. R. Bayliss.

Transactions and Proceedings of the Japan Society, London, Vol. 2, 1892–93, Part 3; from Mr. George Cawley.

Photograph of Members visiting Messrs. Neilson and Co.'s Hyde Park Locomotive Works, Glasgow, 31 July 1895; from Messrs. Neilson and Co.

Service des Eaux de Versailles, Marly, Meudon, Saint-Cloud; from Mr. Henry Chapman.

Bandsägen für Metall-bearbeitung, by Paul Möller; from the author.

The following official publications from the Government of New South Wales:—Annual Report of the Railway Commissioners for the year ending 30 June 1894, with supplement; Annual Report of the Metropolitan Board of Water Supply and Sewerage, 1894; Report of the Department of Public Works, 1893–94; Report of the Department of Mines and Agriculture, 1894; Tenth General Report of the Parliamentary Standing Committee on Public Works; First Progress Report on Hunter District Water Supply and Sewerage Works; Seven Colonies of Australasia, 1894, by T. A. Coghlan; Statistical Register, 1893 and previous years, by T. A. Coghlan; Street-Paving in Sydney, by G. W. Bell.

Official Illustrated Handbook, Colony of Natal, by J. F. Ingram; from the Agent General for Natal.

Annual Report of the Chief of the Bureau of Steam Engineering, United States Navy Department, 1895, from the Bureau.

Catalogue of the Exhibit of the Pennsylvania Railway Co. at the World's Columbian Exposition, Chicago 1893; from the Pennsylvania Railroad Co.

Yorkshire College, Leeds, Annual Report 1893–94; from the College.

Lockwood's Builder's and Contractor's price-book, 1895; from Messrs. Crosby Lockwood and Son.

City and Guilds of London Institute, programme of Central Technical College, 1895; from the Institute.

Cornell University Register, 1894–95; from the University.

Ballarat School of Mines, Calendar 1894; from the School.

General catalogue of West's Gas Improvement Co.; from the company.

Spons' Engineers' and Contractors' illustrated book of prices, 1895–96; from the publishers.

Illustrated catalogue of Machine-Tools; from Messrs. J. Butler and Co.

Illustrated catalogue of Machine-Tools; from Messrs. John Hetherington and Sons.

Illustrated catalogue of Machine-Tools; from Messrs. William Sellers and Co.

Illustrated catalogue of Hydraulic Tools and Machinery; from Mr. Ralph H. Tweddell.

Hand-book of Steel Sections; from Messrs. Dorman, Long and Co.

Illustrated catalogue of Emery Wheels and Emery Grinding Machinery; from the London Emery Works Co.

Report to the Governors of the City and Guilds of London Institute, March 1895; from the Institute.

Calendars for 1895–96 from the following Colleges:—Royal Technical High School, Berlin; Mason Science College, Birmingham; Municipal Technical School, Brighton; University College, Bristol; City and Guilds of London Technical College, Finsbury; Glasgow and West of Scotland Technical College; Michigan Mining School, Houghton, Mich.; Yorkshire College, Leeds; City of London College; King's College, London; Sheffield Technical School.

Civil Engineering College, Sibpur, Calendar 1895; from the College.

Ironmonger diary, 1896; from the publishers.

Board of Trade Reports on Boiler Explosions; from the Board of Trade.

Photogravures of some of the War Ships recently built by Laird Bros. for the British and other Navies; from Messrs. Laird Bros.

Gleanings from Patent Laws of all countries, by W. Lloyd Wise: from the author.

From the United States Geological Survey :—

Fourteenth Annual Report of the United States Geological Survey, 1892-93, by J. W. Powell.

Bulletins of the United States Geological Survey, Nos. 118–122.

The following Monographs of the Survey :—

XXIII. Geology of the Green Mountains in Massachusetts, by Raphael Pumpelly, J. E. Wolff, and T. Nelson Dale.

XXIV. Mollusca and Crustacea of the Miocene Formations of New Jersey, by Robert Parr Whitfield.

The following Publications from the respective Societies and Authorities :—

Reports of the Academy of Science, France.
Annales des Ponts et Chaussées, Paris.
Proceedings of the French Institution of Civil Engineers.
Journal of the French Society for the Encouragement of National Industry.
Annales des Mines.
Annales du Conservatoire des Arts et Métiers.
Journal of the Marseilles Scientific and Industrial Society.
Proceedings of the Industrial Society of St. Quentin et de l'Aisne.
Proceedings of the Industrial Society of the North of France.
Proceedings of the Industrial Society of Rouen.
Proceedings of the Industrial Society of Mulhouse.
Annals of the Association of Engineers of Ghent.
Proceedings of the Society of German Engineers.
Reports of the Royal Academy of Science, Belgium.
Reports of the Royal Institute of Engineers, Holland.
Bulletins of the Commission Internationale du Congrès des Chemins de fer.
Proceedings of the Engineers' and Architects' Society of Canton Vaud.
Proceedings of the Engineers' and Architects' Society of Austria.
Proceedings of the Engineers' and Architects' Society of Prague.
Proceedings of the Architects' and Engineers' Society of Hannover.
Proceedings of the Italian Engineers' and Architects' Society.
Proceedings of the Swedish Technical Society.
Journal of the Norwegian Technical Society.
Journal of the Franklin Institute.
Transactions of the American Society of Civil Engineers.
Transactions of the American Society of Mechanical Engineers.
Transactions of the American Institute of Mining Engineers.

School of Mines Quarterly, Columbia College, New York.
Reports of the Smithsonian Institution.
Report of the Master Car-Builders' Association, New York.
Proceedings of the United States Naval Institute
United States Patent Office Gazette.
Journal of the Association of Engineering Societies.
Journal of the United States Artillery.
Transactions of the Canadian Society of Civil Engineers.
Proceedings and Journal of the Asiatic Society of Bengal.
Proceedings of the Committee of Locomotive and Carriage Superintendents for India.
Proceedings of the Institution of Civil Engineers.
Journal of the Iron and Steel Institute.
Transactions of the Society of Engineers.
Journal of the Institution of Electrical Engineers.
Transactions of the North of England Institute of Mining and Mechanical Engineers.
Proceedings of the South Wales Institute of Engineers.
Transactions of the Institution of Engineers and Shipbuilders in Scotland.
Transactions of the Liverpool Engineering Society.
Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers.
Proceedings of the Cleveland Institution of Engineers.
Transactions of the Mining Institute of Scotland.
Transactions of the North-East Coast Institution of Engineers and Shipbuilders.
Transactions of the Hull and District Institution of Engineers and Naval Architects.
Philosophical Transactions and Proceedings of the Royal Society of London.
Proceedings of the Royal Institution of Great Britain.
Transactions and Professional Notes of the Surveyors' Institution.
Journal of the Royal United Service Institution.
Professional Papers of the Royal Engineers' Institute.
Journal of the Royal Agricultural Society of England.
Report of the British Association for the Advancement of Science.
Report of the Royal Cornwall Polytechnic Society.
Transactions of the Institution of Naval Architects.
Journal of the Royal Institute of British Architects.
Transactions of the Incorporated Gas Institute.
Proceedings of the Physical Society of London.
Proceedings of the Literary and Philosophical Society of Manchester.
Transactions of the Manchester Geological Society.
Proceedings of the Philosophical Society of Glasgow.
Journal of the Royal Scottish Society of Arts.

Transactions and Proceedings of the Royal Irish Academy.
Transactions and Proceedings of the Royal Dublin Society.
Transactions of the Institute of Marine Engineers.
Journal of the Society of Arts.
Journal of the Society of Chemical Industry.
Transactions of the Manchester Association of Engineers.
Transactions of the Junior Engineering Society.
Reports of the Manchester Steam Users' Association; from Mr. Lavington E. Fletcher.
Report of the National Boiler and General Insurance Company; from Mr. Edward G. Hiller.
Report of the Engine, Boiler, and Employers' Liability Insurance Company; from Mr. Michael Longridge.
Report to the Council of the Neapolitan Steam Boiler Association, by Francesco Sinigaglia; from the Association.
Report of the London Association of Foremen Engineers and Draughtsmen.
Twenty-fifth Annual Report of the Bradford Free Public Libraries.
Forty-second Annual Report of the Liverpool Free Public Library.
Forty-third Annual Report of the Manchester Public Free Libraries.
Thirteenth Annual Report of the Newcastle-on-Tyne Public Libraries.
Catalogue of Additions during 1894 to the Radcliffe Library, Oxford.

The following Periodicals from the respective Editors :—

The American Engineer and Railroad Journal.
Arms and Explosives.
The Builder.
Camera Club Journal.
assier's Magazine.
Der Civil-Ingenieur.
The Colliery Guardian.
The Contract Journal.
The Electrical Engineer (from Mr. John T. Ewen).
Electrical Plant and Electrical Industries.
The Electrical Review.
The Engineer.
Engineering.
The Engineering and Mining Journal.
The Engineering Review.
The Fireman.
The Journal of Gas Lighting.
Giornale del Genio Civile.
Glaser's Annalen.
Hardware Trade Journal.
The Indian and Eastern Engineer.
L'Industrie.
Industries.
The Iron and Coal Trades Review.
Iron Trade Circular, Ryland's.
The Ironmonger.
Ironmongery.
Lightning.
The London Technical Education Gazette.
The Machinery Market.

The Marine Engineer.
The Mechanical World.
The Mining Journal.
Phillips' Monthly Machinery Register.
The Plumber and Decorator.
The Practical Engineer.
The Railway Engineer.
Railway Master Mechanic.
The Railway Review.
Revue générale des Chemins de fer.
Revue industrielle.
Revue universelle des Mines.
The Shipping World.
Stahl und Eisen.
The Steamship.
The Textile Recorder.
Transport.

The PRESIDENT, in moving the adoption of the Report of the Council, said that, besides the honours which had been conferred upon Members of the Institution during 1895, in the present year two new Baronetcies had been created, namely those of Sir William Coddington, Bart., M.P., and Sir Wm. Thomas Lewis, Bart. To each of these Members the Council had had the pleasure of offering their congratulations on behalf of the Institution. One other announcement which he should like to make, for he was sure it would receive the cordial approval of all the members, was that at today's meeting of the Council Professor W. Cawthorne Unwin had been nominated as an Honorary Life Member of the Institution. It was known to every member that Professor Unwin represented, probably in a degree in which no other engineer without exception represented, the combination of practical and scientific engineering knowledge and experience of the highest order; and it was a peculiar pleasure to himself that this action on the part of the Council should have been taken whilst he had still the honour of being President.

The motion for the adoption of the Annual Report of the Council with the statement of accounts was then put to the Meeting, and agreed to.

The PRESIDENT moved on behalf of the Council the following Resolution, of which notice had been given in the circular convening the present meeting:—"That in accordance with No. 31 of the Articles of Association the Council be hereby authorized to borrow moneys for the purposes of the Institution on the security of the property of the Institution, or otherwise at their discretion." No. 31 of the Articles of Association was as follows:—"The Council may, with the authority of a resolution of the Members and Associate Members in General Meeting, borrow moneys for the purposes of the Institution on the security of the property of the Institution, or otherwise at their discretion."

Mr. JOSEPH ADAMSON said that as an old member he should be glad to know the reason why the Council wished to alter this rule. As far as his recollection went, the members of the Institution had never refused to find money for anything the Council had recommended. It appeared to him to be rather a large concession, that the members should hand money over to the Council for the time being, without any knowledge or any check as to what was to be done with it.

The PRESIDENT explained that it was not any alteration of the rule which was contemplated by the resolution, but only action in accordance with the rule already existing. The rule provided that the Council could not borrow money without the sanction of a General Meeting. The Council anticipated that in the course of the present year it might become necessary to borrow money in connection with the building of the House for the Institution; and therefore they now asked the sanction of the members at this meeting to their doing so if necessary.

Mr. ADAMSON said he had evidently misunderstood the purport of the notice in the circular, and he had therefore nothing further to say.

The Resolution was then put to the meeting, and carried unanimously.

The PRESIDENT announced that the Ballot Lists for the election of Officers for the present year had been opened by a committee of the Council, and that the following were found to be elected:—

PRESIDENT.

E. WINDSOR RICHARDS, ...	Low Moor.

VICE-PRESIDENTS.

SIR DOUGLAS GALTON, K.C.B., D.C.L., LL.D., F.R.S., ...	London.
FRANCIS C. MARSHALL, ...	Newcastle-on-Tyne.
WILLIAM H. MAW, ...	London.

MEMBERS OF COUNCIL.

HENRY DAVEY, ...	London.
DR. JOHN HOPKINSON, F.R.S., . . .	London.
ARTHUR KEEN, ...	Birmingham.
WILLIAM LAIRD, ...	Birkenhead.
JOHN G. MAIR-RUMLEY, ...	London.
THOMAS MUDD, ...	West Hartlepool.
A. TANNETT WALKER, ...	Leeds.

The Council for the present year will therefore be as follows:—

PRESIDENT.

E. WINDSOR RICHARDS, ...	Low Moor.

PAST-PRESIDENTS.

DR. WILLIAM ANDERSON, C.B., F.R.S., . .	Woolwich.
THE RT. HON. LORD ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., ...	Newcastle-on-Tyne.
SIR LOWTHIAN BELL, BART., F.R.S., . .	Northallerton.
SIR FREDERICK J. BRAMWELL, BART., D.C.L., LL.D., F.R.S., ...	London.
SIR EDWARD H. CARBUTT, BART., . . .	London.
CHARLES COCHRANE, ...	Stourbridge.
JEREMIAH HEAD, ...	London.
ALEXANDER B. W. KENNEDY, LL.D., F.R.S., .	London.
JOHN RAMSBOTTOM, ...	Alderley Edge.

JOHN ROBINSON, ...	Leek.
PERCY G. B. WESTMACOTT, . . .	Newcastle-on-Tyne.

VICE-PRESIDENTS.

SIR DOUGLAS GALTON, K.C.B., D.C.L., LL.D., F.R.S., ...	London.
SAMUEL W. JOHNSON, ...	Derby.
FRANCIS C. MARSHALL, ...	Newcastle-on-Tyne.
EDWARD P. MARTIN, ...	Dowlais.
WILLIAM H. MAW, ...	London.
J. HARTLEY WICKSTEED, ...	Leeds.

MEMBERS OF COUNCIL.

JOHN A. F. ASPINALL, ...	Horwich.
HENRY DAVEY, ...	London.
WILLIAM DEAN, ...	Swindon.
BENJAMIN A. DOBSON, ...	Bolton.
BRYAN DONKIN, ...	London.
DR. JOHN HOPKINSON, F.R.S., . . .	London.
ARTHUR KEEN, ...	Birmingham.
WILLIAM LAIRD, ...	Birkenhead.
JOHN G. MAIR-RUMLEY, ...	London.
HENRY D. MARSHALL, ...	Gainsborough.
THOMAS MUDD, ...	West Hartlepool.
JAMES PLATT, ...	Gloucester.
T. HURRY RICHES, ...	Cardiff.
A. TANNETT WALKER, ...	Leeds.
SIR WILLIAM H. WHITE, K.C.B., LL.D., F.R.S.,	London.

Professor KENNEDY, in virtue of the election which had just been announced, had great pleasure in asking Mr. Windsor Richards to take the chair, which he now vacated in his favour.

Mr. E. WINDSOR RICHARDS, on taking the chair as President, wished to thank the members most sincerely for the high honour they had conferred upon him by electing him President of the

(The President.)

Institution of Mechanical Engineers. It was a position which any one might feel justly proud of having attained. He was aware that the duties which the President was called upon to discharge were often difficult and sometimes onerous, and he should have been loath to undertake them, had he not felt fully assured that he should have the support and assistance of the Council, and also the hearty co-operation of his fellow members. All were proud of the Institution, and were animated by the most sincere desire to do all they could to promote its interests, so that it might continue to prosper and increase in usefulness. During his term of office he could assure them that he would do all in his power to advance the welfare of the Institution. There was one circumstance which had made him hesitate in accepting the nomination of the Council. Although he had been originally and for many years a mechanical engineer, for the last twenty years he had been drifting into the position more of an iron and steel manufacturer than an engineer; and being much occupied in that branch of the profession, he feared he might not be thoroughly conversant with the recent improvements in the best engineering practice. His colleagues on the Council however did not attach so much importance as he did to this circumstance, and he trusted therefore that the members would now accept his best endeavours in the fulfilment of the duties devolving upon him as their President.

Mr. SAMUEL W. JOHNSON, Vice-President, had great pleasure in proposing a vote of thanks to their retiring President, for the distinguished ability with which he had filled the presidential chair of the Institution for the last two years. Professor Kennedy had certainly spared himself neither time nor trouble in the onerous duties which he had performed with such entire satisfaction to the members, all of whom were greatly indebted to him for his exertions, and for the admirable manner in which he had filled the office of President.

Mr. EDWARD P. MARTIN, Vice-President, was glad to have the honour of heartily seconding the vote of thanks.

The President wished to endorse everything that had been said as to the value of the services rendered to the Institution by Professor Kennedy. The members themselves had all witnessed his conduct in the chair at the several meetings, and especially at the two summer meetings in Manchester and Glasgow, where he fulfilled all the trying conditions of both occasions in a manner which was most highly gratifying to every one concerned. But the members could not know all that he had done for the Institution by his attendance at the Council meetings and the numerous committee meetings, which had constituted so great a tax upon his time and thought. His energy and best consideration had been cheerfully devoted, and with the greatest judgment and tact, to all the undertakings of the Institution. It therefore gave him much pleasure to put this resolution to the Meeting, and he was sure the members would show their hearty appreciation of Professor Kennedy's conduct in the chair for the last two years.

The resolution was carried unanimously with applause.

Professor Kennedy thanked the members cordially for the kind way in which they had expressed their feelings towards himself. It would of course be affectation to deny that the duties of the President of an Institution like this were somewhat arduous. Though work of this kind did not make much show outside, yet every one who had had to do it knew that it meant a large amount of attention and of responsibility. It had however been a true pleasure to him to carry out as well as he could the duties of the presidency of this Institution, and to succeed as President such eminent engineers as had previously occupied the chair. He thanked also his colleagues on the Council for the harmonious way in which they had enabled him to work with them during the two years of his presidency.

The President reminded the Members that at the present meeting the appointment had to be made of an Auditor for the current year.

On the motion of Mr. J. F. L. Crosland, seconded by Mr. W. R. S. Jones, it was unanimously resolved that Mr. Robert A. McLean, chartered accountant, 1 Queen Victoria Street, London, be re-appointed to audit the accounts of the Institution for the current year at the same remuneration as at present, namely Twenty-five Guineas.

The following Paper was then read and discussed:—

"Telemeters and Range-Finders for naval and other purposes;" by Professors Barr and Stroud.

Shortly before Ten o'clock the Meeting was adjourned to the following evening. The attendance was 108 Members and 88 Visitors.

The Adjourned Meeting was held at the Institution of Civil Engineers, London, on Friday, 31st January 1896, at Half-past Seven o'clock p.m.; E. Windsor Richards, Esq., President, in the chair.

The following Papers were read and discussed:—

"Calculation of Horse-Power for Marine Propulsion;" by Lt.-Colonel Thomas English.

"Notes on Steam Superheating;" by Mr. William H. Patchell, of London.

The Discussion which had been commenced upon the latter Paper was adjourned, to be continued at the following Meeting.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in allowing the use of their rooms for the Meeting of this Institution.

The Meeting then terminated at Ten o'clock. The attendance was 77 Members and 93 Visitors.

TELEMETERS AND RANGE-FINDERS FOR NAVAL AND OTHER PURPOSES.

BY PROFESSORS BARR AND STROUD.

In this paper it is not proposed to treat of the history of Telemeters or Range-Finders, though that subject would not be devoid of interest. Such instruments cannot be said to be at all in common use, either at sea or on land; yet descriptions of probably some hundreds of different forms have been published, and the workers in this field of invention have included many eminent engineers and physicists, among whom it may be sufficient to name James Watt and Sir David Brewster. A mere classification of the various devices that have been proposed for determining the distances of distant objects without direct measurement would take more time than can be devoted to the present paper. Nor is it proposed to give any account of the different kinds of telemeters that have been devised by the authors themselves in the eight years during which nearly all the time at their disposal for original work has been devoted to invention and experiment in this field. The present paper will be confined to a description of two instruments:—namely (1) the range-finder which is now in use in the navies of this and many other countries; and (2) a small hand instrument, identical in principle with that for naval use, but much more portable and much simpler in its details. Even with this restriction however, it will be necessary to omit the discussion of many of the difficulties that have been encountered, and of the methods by which these have been surmounted.

Principle of Telemeters in general.—Setting aside a few instruments devised for military range-finding, to indicate the distance of the enemy by measurement of the time-interval between the instant when

the flash of one of his guns is seen and the instant when the report is heard, all telemetrical or distance-finding observations (other than direct measurement) resolve themselves into the solution of a triangle, one of whose sides is the range or distance required. Further, in what is usually understood by telemetry, as distinguished from surveying by triangulation, the base of the triangle is extremely small compared with the other two sides. In nearly every case also the triangle to be solved is approximately right-angled; and the operation of finding the distance between two points A and O, Fig. 12, Plate 6, consists essentially either (*a*) in setting out a base AB and determining the angle AOB subtended by it at the point O, or else (*b*) in setting out a given angle AOB and measuring or observing the length AB by which it is subtended. Again the observer may be either at the apex O or at the base AB; and thus there is another mode of classification; namely (*c*) telemeters using a base of known or observed length at the distant object, and (*d*) those working from a base of known or measured length at the observer's station. These are cross-classifications, and the range-finders now to be described belong to the classes (*a*) and (*d*); that is, the base is fixed in length, and it is at the observer's station, not at the distant object. There are a large number of range-finders of this general kind, and these again may be divided into two groups; namely (1) those with a short rigid base of not more than 8 or 10 feet, and usually requiring only one observer; and (2) those working with a longer base, say from 50 to 200 feet or more, and requiring an observer stationed at each end of the base. The range-finders now to be described belong to the former group, as they have bases of 4½ and 2 feet respectively.

The general problem of short-base telemetry will first be stated, and illustrated with reference to the dimensions of the Naval Range-Finder, and to the requirements which it is designed to meet. The naval range-finder will then be described in detail. Afterwards a short account will be given of the small Hand Distance-Finder.

In Fig. 8, Plate 6, is shown a diagrammatic representation of a single-observer range-finder. Two beams of light from the distant object are received by reflectors R_1 R_2, and transmitted through lenses

L_1 L_2 towards the centre of the instrument, where two small mirrors M_1 M_2 are placed, one over the other, to reflect the beams outwards through the eye-piece E_2. By these means two partial images of a distant object are seen in the field of view of the eye-piece E_2, one above the other, as shown in Fig. 10, Plate 6. The image seen in the upper half of the field of view is thus formed by the equivalent of a telescope directed towards the object from the left-hand end of the instrument, while the image seen in the lower half is formed by the equivalent of a second telescope looking at the object from the right-hand end.

Suppose a distant object is viewed by rays shown at B_1 B_2 in Fig. 8, Plate 6; and that the two partial images are seen in correct coincidence or alignment, as illustrated in Fig. 11. If now the object approaches the instrument along the line B_1, the beam of light received by R_2 will have a new direction, such as is shown by the dotted line B'_2; and the partial images will no longer appear in proper coincidence, but will occupy such relative positions as are shown in Fig. 10. The interval between the two partial images might of course serve as a measure of the distance, since the nearer the object comes, the greater will be the interval between the images; but the measurement of this interval would, under any circumstances, be very difficult to make with sufficient accuracy; and it would be impossible to make it even roughly, when the instrument or the object is in motion. Optical or mechanical means are therefore adopted in telemeters of this class, for altering the course of one or other of the beams of light, so that the two partial images may be brought into correct coincidence or alignment, as shown in Fig. 11; and a scale is provided for indicating the distance of the object, the scale (or its index) being moved by the gear used for bringing the images into alignment.

Alignment.—In telemeters of the kind under consideration, in which the range or distance of the object observed is indicated through the operation of a mechanism whereby the partial images are brought into correct alignment, as in Fig. 11, Plate 6, it is not necessary that the axes of the beams of light should fall upon a

particular part of the central reflectors M, Fig. 8. This will be evident from Fig. 9, which shows that a motion of the instrument, or of the object, causes no change in the alignment of the partial images, provided the angle between the rays B_1 and B_2 remains constant. The alignment may therefore be observed in any part of the field, not necessarily in the centre.

Standard of Accuracy.—The Naval Range-Finder was designed to meet the requirements of the Admiralty for an instrument which should be capable of measuring ranges up to 3,000 yards with a maximum error of 3 per cent. In order to have some margin, the standard of accuracy assumed by the authors is that (under favourable circumstances, such as a calm sea and clear atmosphere) the range-finder should be capable of measuring a range of 3,000 yards within 1 per cent.; and this it is found capable of doing. This degree of accuracy will therefore be taken as the basis of calculation in what follows.

The accuracy of any range-finding operation must largely depend upon the nature of the object to be observed, and upon the atmospheric and other conditions under which the observation has to be made. But assuming that the object to be observed is one clearly defined—such as the mast of a ship—and that the atmospheric conditions are favourable, the limit of accuracy which can be obtained will depend, first, upon the length of the base (since this fixes the magnitude of the angle $B'_2\ R_2\ B_2$, Fig. 8, Plate 6, corresponding to any two given ranges); and second, upon the smallness of the angle which the instrument is capable of detecting. In Fig. 13 let b represent the base length of the instrument, that is, practically the distance between the centres of the reflectors R_1 and R_2; and let O be the nearest object whose distance the instrument is to be arranged to measure, say R O = 250 yards (R_1O and R_2O being practically identical in length). Now since the base length b is very short as compared with the distance RO, R_1R_2 may be considered to be an arc of a circle described about O, and the circular measure of the angle $R_1\ O\ R_2$ or $O\ R_2\ B_2$ is

$$\Theta = \frac{R_1 R_2}{R O} = \frac{\text{base}}{\text{minimum distance}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

After having made an instrument of 5 feet base, the authors have adopted $4\frac{1}{2}$ feet or $1\frac{1}{2}$ yard as the base length for the naval range-finders. Taking the distance of O as 250 yards, the angle is $1\frac{1}{2} \div 250$ approximately = 21 minutes or one-third of a degree. This is therefore the angle available for subdivision to indicate the whole series of distances from 250 yards to infinity.

In Fig. 14, Plate 6, let θ represent the smallest angle OR_2O' which the instrument is capable of detecting. Then the difference d of the distances RO and RO′ is only just perceptible; and the error in measurement of a range D may be $\pm\, d$. From the diagram is obtained approximately the ratio $d : e :: D : b$. But $e = R_2O \times \theta = D\,\theta$. Therefore

$$d = D^2 \frac{\theta}{b} \quad . \quad . \quad . \quad . \quad (2)$$

Since θ and b are constant for one instrument, what may be called the *inaccuracy* d of the range D is seen to be proportional to the square of the range. An instrument therefore which can measure 3,000 yards to within 30 yards could measure 1,000 yards to within $30 \div 9 = 3$ yards, and 300 yards to within $30 \div 100$, or say to within 1 foot; while it could measure a range of 6,000 yards to only within $30 \times 4 = 120$ yards, and so on. Moreover since $d = D^2 \dfrac{\theta}{b}$

$$\frac{d}{D} \propto D \quad . \quad . \quad . \quad . \quad . \quad (3)$$

which shows that the percentage of error varies as the distance: so that a range-finder which can work to 1 per cent. at 3,000 yards can work to one-third of one per cent. at 1,000 yards, to one-tenth of one per cent. at 300 yards, and so on.

Equation 2 may be written in the form

$$\theta = \frac{d}{D} \cdot \frac{b}{D} \quad . \quad . \quad . \quad . \quad (4)$$

and taking as the standard an accuracy $\dfrac{d}{D}$ within 1 per cent. at 3,000 yards for a base length of $1\frac{1}{2}$ yards, $\theta = \dfrac{1}{100} \cdot \dfrac{1\frac{1}{2}}{3000} = \dfrac{1}{200{,}000}$.

The angle whose circular measure is unity contains about 206,000 seconds. Therefore $\theta = 1$ second is the angle which the instrument must be able to detect.

Few people have any clear conception of what one second of angle means. In Fig. 15, Plate 6, is represented an angle of 10,000 seconds. The range-finder therefore has virtually to divide this angle into 10,000 equal parts, in order to read a range of 3,000 yards to 1 per cent. An angle of one second is approximately the angle subtended by 1–100th of an inch at 170 feet. As another illustration, let the distance RO in Fig. 16 represent 3,000 yards, or say $1\frac{1}{2}$ nautical miles; and let OO′ represent one per cent. of this, or 30 yards. Then it is required to distinguish between the angles made with the base at R_2 by the lines from O and from O′; and in Fig. 16 the base length R_1 R_2 is exaggerated one hundred fold in relation to the rest of the diagram. As another illustration of the minuteness of the angle indicated in such observations, it may be recollected that an ordinary 5–inch surveyor's theodolite is graduated to read by vernier to one minute. A circle 25 feet in diameter would be required in order to read one second of angle with like facility.

It may be interesting to enquire into the degree of accuracy that can be obtained at very long ranges. The longest range that can be distinguished from infinity, with the foregoing standard of accuracy, is the distance at which the base length of $1\frac{1}{2}$ yard subtends an angle of one second. This distance, which would just be visibly short of infinity, if a clearly defined object could be seen at such a distance, is therefore $D = 1\frac{1}{2}$ yard $\times$ 200,000 = 300,000 yards: say 150 nautical miles or 170 land miles. Of course the curvature of the earth renders objects near the sea-level invisible at distances much within this limit. The range-finder and the object viewed would each require to be about 5,000 feet above the sea-level in order to render the object visible over the sea. Two distances D_1 and D_2 should be capable of being distinguished (always supposing that the objects are clearly defined) when $\frac{b}{D_2} - \frac{b}{D_1}$ is not less than $\frac{1}{200,000}$;

that is, if $\frac{D_1 - D_2}{D_1 D_2} b = \frac{1}{200,000}$, D_1 and D_2 can just be distinguished. For example let $D_1 = 20$ nautical miles, or say = 40,000 yards; then if $\frac{40,000 - D_2}{40,000 D_2} = \frac{1}{200,000}$, the value of D_2 becomes about 33,000 yards, or say $16\frac{1}{2}$ nautical miles; therefore the observer would just be able to say that an object was not less than $16\frac{1}{2}$ nautical miles distant and not more than 20. Similarly he would just be able to say that another object was not less than 9 and not more than 10 nautical miles away.

At short ranges the accuracy becomes very great. At 1,000 yards the error should not exceed about 3 yards, at 500 yards about 2 feet, and at 250 yards about 7 inches.

Methods of producing Alignment.—Fig. 17, Plate 7, is a diagrammatic representation of the telemeter devised in 1860 by Mr. Patrick Adie, in which the objectives were fixed in front of the end reflectors, and one of the reflectors R_2 was fixed to a long arm A, which was caused to move about a pivot at C near the centre of the instrument, by means of a micrometer screw S acting on the outer end of the arm. By thus turning the reflector R_2 through a very small angle, the alignment of the images was effected; and the reading of the micrometer then indicated the range. To attain the standard accuracy of 1 per cent. at 3,000 yards, this angular motion of the reflector would require to be effected correctly to within $\frac{1}{2}$ second of angle (since when a mirror is moved through any angle the course of a ray reflected from the mirror is altered by twice that angle); and taking the length of the arm as 27 inches, and the base length $1\frac{1}{2}$ yard, the micrometer would require to move the end correctly to $27 \div 400,000$, say 1–15,000th of an inch. Therefore any want of truth in the micrometer screw, or any springing of the arm, sufficient to affect the motion of the end by this small amount, would be fatal to the attainment of the standard accuracy. In the instrument devised in 1886 by Mr. W. H. M. Christie, Astronomer Royal, shown diagrammatically in Fig. 18, one of the objectives L_1 is caused to move transversely in the tube by means of a micrometer

screw S, its motion causing an equal motion of the image formed by it. For example in Fig. 8, Plate 6, in order to effect alignment of the partial images of the object from which the rays B_1 and B'_2 emanate, it would be necessary to move the objective L_2 transversely towards the observer through a distance equal to the distance between the full line and the dotted line at the central reflector M_2. For one second of angle on a base of 4½ feet this distance is approximately 26÷200,000, say 1–8,000th of an inch.

In the instrument devised in 1888 by the authors, shown diagrammatically in Fig. 19, Plate 7, the partial images are brought into alignment by means of an achromatic refracting prism P of small angle, which is placed in the path of the rays from the right-hand reflector R_2, and is movable longitudinally in the tube. The action of this prism is illustrated in Figs. 19 and 20, from which it will be seen that, when the prism is moved from the position P to the position P′, the image of the object viewed moves from C′ to C; and thus, while the partial images of a very distant object seen by rays B_1 and B_2 appear in coincidence when the prism is at P, the prism must be moved to P′ in order to cause alignment of the partial images in the case of a nearer object which sends beams B_1 and B'_2 to the instrument. If, instead of a prism P, a piece of glass having parallel faces were used, it is evident that a longitudinal motion of such a glass from P to P′ would cause no transverse motion of the image; and therefore by making the angle of refraction of the prism small enough, as large a longitudinal motion as may be desired will correspond to a given motion C′C of the image, that is, to a given change of range.

Refracting prism.—The prism used in the naval range-finder deflects a ray of light through an angle of 1 in 40, or nearly 1½°; and this prism requires to be moved through about 6 inches for a change of range from infinity to 250 yards, and the motion corresponding to one second of angle is about 1–200th of an inch. This dimension is one which can easily be read directly by aid of a magnifying lens, so that no micrometer gear is required either for effecting the motion or for indicating its amount.

Scale.—It is evident then that the position which the refracting prism occupies when alignment of the partial images has been attained constitutes an indication or measure of the range; and therefore a scale S, Fig. 19, Plate 7, connected to the prism P and moving with it, can be so graduated as to indicate the range directly in yards or other units. The refracting prism P is moved longitudinally in the tube by means of a screw; but any imperfection or slackness in the screw will produce no errors in the indications of the instrument. The alignment or want of alignment of the partial images depends only upon the position of the refracting prism, supposing the end reflectors and other parts of the instrument to remain undisturbed; and as the scale moves with the prism, it always indicates the same range for any given position of the prism. Therefore, even if the working screw were so irregular or "drunk," that for a continuous rotation it moved the prism first outwards and then inwards, both the images and the scale would be moved accordingly; and hence no errors would be introduced, such as would result if the rotation of the screw itself were made to measure or to indicate the range, as in the case of micrometer devices.

From Fig. 8, Plate 6, it is clear that a change of direction of the right-hand ray through any angle, as from B_2 to B'_2, produces a transverse displacement of the image proportional to the angle between these two directions. Further, from Fig. 20, Plate 7, it is evident that if the refracting prism be moved through any distance, say 1 inch, the image will move transversely through 1–nth of an inch, where $1 \div n$ is the tangent of the angle of deflection produced by the prism, or 1 in n is the deflection stated as a gradient. The magnitude of the transverse motion is therefore proportional to the distance the prism is moved, and is independent of the distance of the prism from the image. Equal longitudinal motions of the refracting prism therefore correspond to equal changes of angle; and, as in Fig. 13, Plate 6, $\Theta = \frac{b}{D}$, and b is constant, it is seen that the angle Θ—that is, the angle between the ray from an infinite distance and the ray from an object at distance D, the left-hand ray maintaining a constant direction—varies as the reciprocal of the

distance. The scale to be attached to the refracting prism for indicating the distance directly is therefore a reciprocal scale, that is, the graduation representing 2,000 yards is midway between the infinity mark and that representing 1,000 yards; and so on, as shown in Fig. 21, Plate 7. The actual scale is much more minutely subdivided, being graduated to single yards up to 500, in tens of yards to 1,500, in hundreds to 5,000, and in thousands to 10,000. Graduations are also made for 15,000 and 20,000 yards.

The moving refracting prism may be looked upon as a perfect mechanism for the purpose of magnifying the required motion of the image, inasmuch as a motion however minute of the prism necessarily produces an exactly corresponding though much smaller motion of the image formed by rays traversing it. In this optical mechanism therefore there can be absolutely nothing which would correspond to slackness or lost motion in a screw, or to irregularity or "drunkenness" of a micrometer, or to springing of a mechanical device for magnifying or reducing a given motion.

The scale, which is made of ivory so as to be translucent, is carried inside the tube T, and is illuminated by light entering through a lens F, Fig. 19, Plate 7, and Fig. 22, Plate 8. It moves past an index I fixed to the framework of the instrument, Fig. 19. Opposite the index is placed the scale lens E_1, which is at a distance of $2\frac{1}{2}$ inches from the eye-piece E_2, so that, when the right eye is placed at the eye-piece E_2, the left eye is opposite the lens E_1; and thus, when correct alignment of the partial images has been attained, the scale can be read instantly without the observer shifting his eyes. After a little practice it is found easy to use the two eyes either alternately or simultaneously for their respective duties; and the object need not be lost sight of in the range-finder while the scale is being read. The great importance of thus keeping the object continuously in view will be evident, when it is remembered that at sea the instrument is not upon a steady platform, and therefore does not keep on the object as a theodolite does when left to itself. Furthermore, the range of a distant ship, or of a lighthouse, may be rapidly changing, and it may be necessary to take frequent readings of the changing distance.

Finder.—In order to overcome the difficulty of finding in the first instance the object whose range is required—a difficulty greatly increased by the motions incidental to a ship at sea, and by the fact that the observer here looks across the tube of the instrument, instead of along its length—a finder of simple construction is provided in the instrument. In Fig. 23, Plate 8, which shows the field of view for the left eye, it will be seen that the scale occupies only a portion of the field, and is placed entirely above the centre line of the instrument. Underneath it a clear space is left, so that direct light comes through the objective F, Figs. 19 and 22, to the lens or left eye-piece E_1. Only the upper half of the left eye-piece is taken up by the convex scale-lens, or rather half-lens; while in the lower half there is provided a concave lens, or rather half-lens, Fig. 22. This concave lens and the objective F constitute a small Galileo's telescope, as in an ordinary opera-glass, through which a view is obtained as is indicated in the lower part of Fig. 23. The magnifying power of this telescope is small, and the objective is large in diameter, so that the field of view is wide, and there is no difficulty in immediately sighting the object whose range is required. The finder is so adjusted that, when the object viewed is brought into the centre of its field, as shown in Fig. 23, it will be found, greatly magnified, in the much more restricted field of the right eye-piece, Fig. 10, Plate 6. The left eye has therefore two duties to perform; and the process of taking a range consists (1) in finding the object by means of the left eye, and bringing it into the centre of the left-eye field; (2) in adjusting into correct alignment the partial images as seen in the right-eye field; and (3) in reading the scale by the left eye. This arrangement renders the instrument so convenient to work that it is found possible at sea to determine the range of an object in from eight to ten seconds from the time the observer reaches the instrument.

Reflectors.—In the first instruments they designed, the authors adopted totally reflecting glass prisms for the end reflectors R_1 and R_2, Fig. 19, Plate 7. The fixing of such prisms securely enough, and at the same time without deformation of their optical faces, they understand has been one of the principal difficulties encountered by

others in the design of telemeters of the class under consideration. Since the motion of a reflector through any angle produces a motion of the reflected ray through double that angle, it is necessary for the attainment of the standard accuracy, as already pointed out, that neither of the reflectors, nor indeed the two relatively to each other, should move through an angle of half a second, that is to say an angle of 1 in 400,000. If then the length of the reflector be taken as two inches, one end must not move relatively to the other through 1–200,000th of an inch. The authors ultimately succeeded in fixing such prisms by forming grooves upon their upper and lower surfaces, clamping them lightly between the top and bottom members of the frame-work of the instrument, and securing them by means of a hard cement used in dentistry. Latterly however they have adopted, instead of reflecting prisms, speculum-metal reflectors, since these may be fixed by screwed and soldered connections. The composition of the speculum metal used is that given by the late Lord Rosse (Lord Oxmantown), namely, copper 126·4 and tin 58·9, or four equivalents of copper to one of tin (Philosophical Transactions 1840, page 503).

In the foregoing description of the general construction of the range-finder, and in Fig. 8, Plate 6, the central reflectors M_1 M_2 have been represented as consisting simply of one mirror placed over another, the two mirrors being at right angles to each other, and each having its plane inclined at 45° to the axis of the instrument. Such a pair of mirrors is shown in Fig. 24, Plate 8. If the eye-piece of the instrument were focussed upon the point of crossing of these mirrors, it is evident that the ends would be quite out of focus; and therefore, instead of a clear line of separation between the two portions of the field, as shown in Fig. 10, Plate 6, the central part only of the line of separation would be clearly defined, while at the edges the two fields would more or less overlap each other. In order to avoid having a line of separation in focus at one part of the field, and quite out of focus at other parts, the images of the object may be made to fall some considerable distance in front of the reflectors: in which case there would be no line of separation, but the partial images would overlap in some such manner as is represented

in Fig. 25, Plate 8. Such overlapping images however show only what may be called ghosts of the object viewed, inasmuch as the background is visible through each. Thus a mast or flagpole seen against the sky does not appear opaque, but has the skylight of the other image superimposed upon it, as indicated in the figure. Any want of exact alignment is then indicated only by a greater or less amount of faint doubling at the edges of the object; and by careful experiments the authors have found that under these circumstances alignment cannot be made with at all the same degree of exactitude as is possible when the partial images are clearly separated from each other and each appears opaque, as is represented in Fig. 10. Another objection to a simple pair of mirrors, such as is shown in Fig. 24, is that the nearer mirror obstructs some of the rays reflected by the more distant mirror; and therefore the images are not formed with the full amount of light transmitted from the objectives.

Eye-piece Prism Combination.—The design of an optical combination which would avoid this latter defect, and would also give a clearly defined line of separation between the images, has occupied a great deal of the authors' time and attention during the whole of the eight years they have worked at this subject; and many different arrangements have been devised, which accomplish, with greater or less success, the purpose in view. The plan which is now adopted will alone be described. It is called an eye-piece prism combination, and is shown in Plate 9, in plan in Fig. 28, and also in elevation in Fig. 29 as seen from the right-hand end of the instrument. A ray of light U, coming from the left-hand end of the instrument, is totally reflected from the face f_1 of the prism M_1, Fig. 28, so as to strike the face f_2, Fig. 29, which reflects it downwards to f_3, whence it is again totally reflected so as to pass towards the eye-piece with a downward inclination, till it strikes the face f_4 of a prism M_3. In passing into the prism M_3 it is refracted into a horizontal direction. In like manner a ray from the right-hand end of the instrument takes such a course as that represented by the dotted line. A ray from the right-hand end, which follows such a course as that represented by the dot-and-dash

line, passes through the prism M_3 at such an angle that it fails to enter the eye of the observer. If the objectives are so placed that the images are formed in the vertical plane containing the edge E, the eye-piece can be so adjusted as to bring the images and the edge simultaneously into focus; and from what has just been seen with respect to the course of the ray represented by the dot-and-dash line, it is evident that the portion of the image formed by the right-hand objective, which falls below the edge line E, is quite out of view, as is also the portion of the image formed by the left-hand objective, which falls above the edge E. The edge therefore forms a clear line of separation between the images; and being situated at right angles to the axis of the eye-piece, the whole length of the line is in focus. It is possible for an optician to grind such a prism as that shown at M_3 with an exceedingly sharp though obtuse angle at E, and consequently a narrow but clear line of separation can be obtained. The face of the prism M_3 nearest the eye may conveniently be ground to a spherical form, as shown in Plate 9, so that it constitutes the field lens of a Ramsden eye-piece, such as is commonly used in theodolites and other surveying and astronomical instruments.

An interesting and important feature of this optical combination is that it re-inverts the image of the object, so that the object now appears erect: instead of being inverted, as it is in a telescope consisting of an object-glass and a simple eye-piece. Thus in Fig. 29, Plate 9, a ray of light coming from the upper part of the object will strike the eye-piece prism M_1 lower down than one coming from a lower point. If the thicker line in Fig. 29 represents a ray from the upper part of an object, and the thinner line a ray from a lower point, it is evident from the figure that when these reach the image the thicker ray is again uppermost, so that the object appears erect instead of being inverted. In like manner the combination causes the object to appear unreversed, that is, right for right: instead of reversed right for left, as it does in a simple telescope. This eye-piece prism combination the authors believe leaves nothing to be desired.

Astigmatiser.—In Fig. 10, Plate 6, the object viewed is represented as being a pole or a mast. When, instead of an object having long

vertical edges, a single point is to be observed, such as a star or a distant light, it is evident that it cannot be divided into two by the separating line, and therefore its range cannot be determined by the alignment of two partial images, in the way above described and illustrated. The adaptation of the instrument for the determination of the distances of lights—which is one of the most important uses for a telemeter, especially at sea—was therefore one of the greatest difficulties the authors had to face. It was ultimately overcome simply and effectually by placing in each of the two beams of light—in that from the right-hand end of the instrument, and in that from the left-hand end—a small cylindrical lens, having the axis of the cylinder horizontal and transverse to the direction of the beam. The effect of such a lens is practically to put the light greatly out of focus vertically, while not disturbing its focus horizontally. A speck of light is thus drawn out into a long vertical streak in each partial field, as represented in Fig. 26, Plate 8; and the alignment can therefore be effected exactly as in the case of a mast. When the particular eye-piece prism combination already described is used, the two lenses can be made in one piece, as shown at A in Fig. 30, Plate 9. This cylindrical lens arrangement, which is called the astigmatiser, can be instantly put into the course of the beams, or taken out, as may be desired. It is found of great advantage in some cases to use the astigmatiser on other objects than single lights. For example, such an object as a tree when astigmatised appears as a mass of vertical streaks, which can be worked upon much more easily than would be the case with the simple image. Or again, when a torpedo boat is illuminated under the action of a search light, it appears studded over with glittering spots and patches; the astigmatiser causes these to be drawn out into a comb of bright lines, somewhat as shown in Fig. 27, Plate 8, and the boat is thus rendered a remarkably easy object to observe upon for determining its distance.

Frame.—Thus far the telemeter has been described only as an arrangement of optical parts. These now require some mechanical support in the shape of a tube or other frame-piece, upon which they may be mounted; and in view of the necessity for absolute

steadiness in the support of the end reflectors, it is evident that any deformation of the frame-piece, such as will cause one reflector to move angularly in relation to the other, will cause an error in the indications of the instrument. It is therefore necessary to secure that no appreciable permanent strain of the frame shall be likely to result from the treatment to which the instrument will be subject in transport and in ordinary handling say on board ship ; and further that the external forces necessarily applied to the instrument during use, and the changes of temperature to which it will be exposed, shall cause no temporary deformation of measurable amount. With a view to minimise the errors from the latter cause, the use of a tube as the support for the optical parts of the instrument has been discarded, and a frame-work composed of copper bars has been adopted, Plates 3 to 5. As a primary protection against deformation from external forces, the instrument proper is inclosed within an outer tubular case, Plates 1 and 2, from which it is supported in such a manner that, though the case itself may be strained by external forces applied to it during the use of the instrument, no strain is thereby communicated to the frame-work supporting the optical parts.

The upper and lower members of the frame-work consist of wire-drawn copper bars, of the section shown at W in Fig. 37, Plate 12, while the bracing is formed of another bar of the section shown at Z. A length of the latter bar is bent into a zigzag form, after it has been grooved transversely at the proper intervals, and has had the requisite holes cut in it for forming the tunnel through which the beam of light may pass. The top and bottom facets are next milled out to fit the section of the upper and lower members, which are then securely soldered to the zigzag, so as to form what may be called a girder with perforated plate bracing. It is important that the frame-work should be as stiff as possible in a horizontal plane, much more important than that it should be stiff vertically. Considered therefore simply as a girder, the frame is, so to speak, turned with its side towards the forces it has principally to resist, inasmuch as its stiffness is evidently greater in a vertical plane than in a horizontal ; but there are good reasons for placing it thus.

As compared with a tube, the frame-work has great advantages in the ease it affords for erecting the optical parts, and for getting all the mechanical parts into working order, because each part is here separately accessible without disturbing the others. Again, the bracing presents a series of diaphragms, which most effectually exclude stray light reflected from the sides of the outer casing. But the chief reason for adopting this form of frame, and for constructing it of copper, is that liability to error from differential heating of the front and back of the instrument is thereby greatly reduced. In Fig. 38, Plate 12, is shown a section of a tube, and in Fig. 39 a section of the frame-work, each enclosed within an outer tubular casing. If heat is radiated upon the casing, as shown by the arrows, and heats the portion of the outer casing upon which it strikes, it is evident that heat will in turn be radiated inwards upon the tube or frame-work of the instrument; but while the tube in Fig. 38 presents the whole of its half circumference to the radiant heat, and that half completely screens the opposite half from the radiation, the open frame-work in Fig. 39 presents a much smaller surface to receive the heat, and moreover some of the heat is radiated directly through the open spaces to the remote edges of the frame, and helps greatly to maintain a balance of temperature. Besides this, the members of the frame being in the form of transverse planes, give the shortest route possible for the heat to get across from the one side to the other. Were the girder laid so as to have its plane of maximum stiffness horizontal, the conditions would evidently be much less favourable to uniformity of temperature on the front and back faces. Any bending of the frame-work in a vertical plane, when the instrument is directed towards the horizon, produces no observational effect, whether such bending is due to external forces or to a difference in temperature between the upper and lower members of the frame.

Case.—In order yet further to retard and also to equalise the transmission of heat to and from the frame, the case or outer tube is made of two concentric tubes, separated by distance pieces, Fig. 31, Plate 10. The inner shell is of copper, while the outer is of brass and is enamelled externally. It was intended if necessary to fill

partially the intervening space with water or other liquid; but it is found that air answers all the requirements. Any fluid in contact with the warmed side of the outer shell of the case will tend to rise, and so to cause a differential temperature between the top and bottom members of the frame, instead of between the front and back, and thus will produce no effect upon the indications of the instrument. The necessity for great care in the design in this respect may be illustrated by mentioning that a difference of temperature of 1–200th of a degree centigrade, or 1–110th of a degree Fahr., between the front and back edges of the frame-work, would produce an error of 1 per cent. at 3,000 yards.

Supports of Frame-work.—It is necessary not only that the frame-work should not bend through differential heating, but also that no forces applied by the hands and face of the observer should strain it. The delicacy with which this has to be accomplished may be gathered from the fact that, while the frame-work is amply strong enough to resist permanent deformation from the weight of a man standing upon it, yet a horizontal pressure of only 2 ounces applied at the centre is sufficient to cause an error in the reading. It is therefore essential that no appreciable bending forces shall be applied to the frame during the use of the instrument. This is secured by attaching all the accessible parts, including the eye-pieces and the driving gear for the working screw, to the outer tube or case; and by so supporting the frame-work from the outer tube that any bending or twisting of the case itself shall transmit no forces to the frame-work. To this end the frame-work is supported from the outer tube or case at two places, situated at about 17 inches to the right and 17 inches to the left of the centre of the frame. At the left-hand side the frame-work is supported by a simple gimbal-ring arrangement, as shown in Fig. 31, Plate 10, which prevents the frame-work from moving longitudinally and also from rotating within the outer case. At the right-hand side another form of support is necessary, inasmuch as at this end it would not do to constrain the frame against endwise motion, nor yet against rotation, seeing that such constraint is already involved in the left-hand support. The right-

hand support is therefore made in the manner shown in Fig. 32, where SSS are three short struts or rockers, with their outer ends resting in cups fixed to the outer case, and their inner ends resting in cups fixed to the frame-work. This arrangement is kinematically equivalent to a rod passing through a fixed ring formed of round wire; that is, it permits of free motion endwise, free rotation, and free angling, while it affords constraint against transverse motion. This system of supports is found completely to answer its purpose, and no forces applied to the outer tube affect the indications of the instrument. The exact position of the points of support on the frame are determined by calculation and experiments. If supported quite at its ends, it is evident that, in virtue of its own weight and of the weights of the parts it carries, the frame would become concave upwards when directed otherwise than horizontally—say towards a star above the horizon; whereas if supported at the centre only it would become convex upwards. In the former case the star would read short of infinity; and in the latter case *beyond* infinity, if such an expression may be allowed in view of the nature of the scale. The exact nature of the problem of the correct balance is rather difficult to state, but it will be evident that there is a certain condition to be attained, in respect to the nature of the deflections produced by gravity under the foregoing circumstances.

In order to prevent rain, spray, or dust from gaining access to the internal parts of the instrument, and to prevent currents of air from affecting the balance of temperature, circular windows of optically worked parallel glass are attached to the case in front of the end reflectors; and the adjusting heads, which must be accessible from outside, are enclosed in pockets in the ring, Fig. 32, Plate 10.

Gear.—As already explained, the accuracy of the telemeter does not depend at all upon the perfection of the gear by which the refracting prism is moved to and fro. Nevertheless it is advisable to have the gear as free as possible from slackness or lost motion, because in the working of the instrument it tends towards rapidity and ease of observation if every motion of the working head, however slight, produces a corresponding motion of the prism. The

working screw and the nut which runs upon it are therefore made with great care. In Figs. 33 and 34, Plate 11, is shown the arrangement of the driving gear. The screw G is 5–16ths inch diameter, cut with 20 threads per inch, double thread. A nut about 1 inch in length is tapped to fit the screw, and afterwards is slotted open, as shown. The nut is machined out on its under surface to the stepped form shown, and is then cut into two in the middle of its length; and the two parts are soldered 2 inches apart to a plate P having a truly straight edge. By this means the two portions N_1 N_2, each half an inch in length, are held truly co-axial, and the equivalent of a nut 3 inches in length is obtained. The split nuts are bound by screws, so that they can be tightened up to the requisite degree; and they are carefully ground upon the screw with a fine grinding powder.

The spindle of a helically cut pinion W_2, Fig. 33, Plate 11, which is supported in the ring carrying the three struts, Fig. 32, is connected to the screw through the medium of a loose piece L, provided at each end with couplings C_1 and C_2. These couplings are of the simple construction shown in the detail views, Figs. 35 and 36; and are designed to prevent any force, other than that of a simple torque, from being communicated from the ring, which is attached to the outer case, to the screw G, which is supported in bearings from the frame-work. They permit of free angling of the one shaft relatively to the other, and also of free motion endwise, while communicating rotary motion from the pinion to the screw. The pinion W_2 is driven by a wheel W_1; the latter passes through a hole in the outer case, and is housed in a box X, which prevents rain or dust from gaining access to the interior of the case. The wheel W_1 is carried on the spindle of the working head H, which is milled to the form of a series of toothed wheels. The fingers of the operator are placed over the working head, the toothed and grooved surface of which gives a good bite, and renders the head easily workable, without being gripped in the fingers.

In some of the earlier instruments, a simple device was adopted to avoid all shake or lost motion in the gearing W_1 W_2, Fig. 33, Plate 11, which the authors do not remember having seen described.

The gear W_1 was made of two narrow wheels, placed side by side, one loose and one fast on the spindle of the working head H. The two wheels were permitted a relative motion equal to only a fraction of a tooth; and a small spring was provided which tended to force them out of correspondence. When such a wheel is brought into gear with the pinion W_2, it will be seen that, if the spring be strong enough to communicate the rotary force necessary for driving the screw G, a "space" in the pinion will always be completely filled by the equivalent of an expanding tooth on the wheel; and lost motion or back-lash will be impossible. The friction caused by the arrangement is not excessive. This device however is not deemed necessary, and for the present at least has been abandoned in favour of solid helical gear.

Adjustments.—Two adjustments have to be provided for. One, called the "coincidence" adjustment, is to effect the condition that the scale shall read the true distance of the object when alignment has been attained; or rather, considering the method employed for accomplishing the adjustment, it secures that, when the true distance of an object is indicated by the scale, the images shall be in correct alignment. The refracting-prism holder D, Figs. 33 and 34, Plate 11, is not attached directly to the nut on the working screw G. The plate P, carrying the two portions N_1 N_2 of the nut already described, carries also a fork F which fits into a neck on the screwed sleeve K. This sleeve, upon which the prism-carrier D is mounted, slides upon the rod R, which is grooved throughout its whole length, and is driven from the spindle V of a milled head, Fig. 33, carried in bearings in the ring that encircles the frame-work, Fig. 32, Plate 10. The connection between the end of the rod and the spindle of the milled head is made through the medium of a loose piece and couplings similar to those for driving the working screw G. The rod R is supported in bearings in the brackets Q_1 Q_2. The prism-holder D is prevented from rotating about the rod R by being forked on to the plate P. It will thus be evident that, when the rod R is rotated, the prism-holder D will move relatively to the nut N_1 N_2. The scale however is connected rigidly to the nut; and consequently,

when the rod R is rotated, the prism is moved, while the scale remains stationary. In order therefore to effect the adjustment of the instrument for "coincidence," the scale is set to read infinity, and a star or the moon is sighted; and if the images do not appear in exact alignment, the rod R is rotated until true alignment is attained.

The second adjustment which requires to be provided has, for want of a better term, been named the "halving" adjustment. Its purpose is to fulfil the condition that, when the two partial images of an object are brought into alignment, they shall form a complete image, and show neither duplication nor deficiency of the part of the object that falls at the separating line. For this purpose one of the partial images must be movable relatively to the other in the direction at right angles to the separating line. Such motion is produced by the gear shown in Fig. 40, Plate 12. A plate of glass G, having truly worked flat parallel faces, is placed in the course of the beam from the left-hand objective, and is free to rotate partially about a horizontal axis at J. When the glass is directed normally to the beam, the latter suffers no displacement in transmission; but when the glass is angled, it causes an upward or downward displacement of the beam, according as it is directed as shown in Fig. 40, or with the opposite inclination as indicated by the dotted line. This gear is worked by means of a screw H, attached to a shaft lying along the upper side of the framework; the shaft is connected, by means of couplings of the kind previously described, with the spindle Y of a milled head carried in bearings in the ring, Fig. 32, Plate 10.

In order to prevent accidental interference with the adjusting heads, these are covered by a revolving ring on the outer case; and the ring is fixed in the closed position by a locking screw, except when adjustments are to be made. Though provisions for adjustment, such as those described, must obviously be made for meeting cases of accidental derangement, it is found in practice that they are seldom required. For example, the authors understand that the first instrument supplied to the Admiralty, which was adjusted in Glasgow and despatched by train to Portsmouth, had not required adjustment during seven months' use at sea; they are not aware whether or not it has since required adjustment.

Electric Lamp.—In order to illuminate the scale at night, an electric lamp of one candle-power, having a bulb about $\frac{1}{4}$ inch diameter, is housed in a metal box attached to the outside case, Fig. 22, Plate 8. The light from this lamp passes through a small window in the outer case, and is reflected from a mirror on to the scale and index point. The lamp is connected with a small portable secondary battery of three cells, carried upon the stand of the instrument; the leads are carried for a portion of their length between the two shells of the outer case. In the course of the leads there is placed a push switch, close to the working head: so that, when using the instrument at night, the observer can at once illuminate the scale when he has effected the alignment of the images.

Stand.—For use on board ship, the instrument is mounted upon a stand, Plates 1 and 2, having provision for allowing the instrument to be turned freely in azimuth about a vertical axis, and also to be directed at a constant altitude in spite of the rolling or pitching of the ship. It is not intended on the present occasion to describe the stand in detail, as the authors believe the particulars already given of the telescopic part of the instrument embody the most novel features of the apparatus, and those that will be of greatest interest to the members of the Institution.

The provisions already described for the exclusion of rain &c. render the instrument capable of exposure to all weathers. Nevertheless it is of course advisable, when the instrument is to be out of use for some time, to remove it from its stand, and place it in a box provided for the purpose, Plates 1 and 2, in which it is held by means of india-rubber pads and leather straps, whereby it is secured against accidental damage. The box is fixed upon the deck near the range-finder stand.

Use of Instrument.—In the conditions accompanying the invitation which the authors, in common with a few others, received from the Admiralty to submit a range-finder for use in the navy, the determination of the range of an enemy's ship for purposes of gunnery was no doubt the main object in view. The instrument has

however proved of great value for purposes of navigation. It is well known that the distance of any object at sea, and more especially the distance of a light, cannot be estimated by eye with any approach to accuracy. So much is this the case that, in certain weathers, experienced navigators frequently mistake the light of a distant light-house for a near ship's light, and *vice versâ*. The only methods ordinarily available to the navigator for determining the distances of objects on shore are (1) by observing the change of bearing of the object in steaming a known distance, or (2) by "cross bearings" when the bearings of two known objects on shore are simultaneously observed, the position of the ship being deduced by plotting the bearings on a chart. In many cases, especially at night, only one object (say the light of a light-house) is available, in which case the first method is the only one possible; but this again is inapplicable when the light is within some points of the bow; and this is the most important case, inasmuch as it means that the ship is steaming towards the danger. Even in the most favourable case, namely that of steaming past a light, the method requires the lapse of a considerable amount of time, and may involve incurring great risks. The range-finder will determine the distance of the light of a light-house or other object in a few seconds; and when necessary the object can be kept constantly in view, and the distance be read as frequently as may be desired.

When the range is changing—either from the motion of the ship carrying the range-finder, or from the motion of the object, or from both—the range-finder can be used in either of two ways: (1) the object may be kept constantly in view, and the range read as frequently as desired, say every two or three seconds; or (2) the scale may be set to read a range that is being approached, and the range-taker, without touching the working head, may watch the images approaching each other, and give the word when exact alignment has been attained. This latter method of operation is specially applicable when the instrument is used in connection with gunnery, because the guns and the range-finder can be adjusted for the same range, and the guns fired at the instant that the range has been attained.

The range-finder will no doubt be found of great service in carrying out experiments on the manœuvring qualities of ships. For example, the turning circle (or, more correctly speaking, the turning curve) of a ship, under given circumstances, can be determined by causing the ship to turn around or near a floating object—say another ship, or a small boat or target carrying an upright pole: determining the distance and the bearing of the object simultaneously at given intervals of time, and plotting the data thus obtained. Again, the speed of a ship can be determined by causing it to steam past a stationary ship or a small boat, and noting the instant when the object is say 1,000 yards ahead, and again the instant when it is 1,000 yards astern. The speed of the ship could no doubt be ascertained in this way with quite sufficient accuracy for all practical purposes, and indeed well within the variations of the speed that result, under nominally identical circumstances, from unknown causes—say within 1 per cent. As this trial does not necessitate taking the ship off duty to a measured mile, it could, especially in the case of war vessels, be carried out frequently, and under a great variety of circumstances. It will be evident also that as the ship and the floating object partake alike of the motion due to any general current, the effect of such a current is eliminated.

The value of the instrument for nautical surveying will be so obvious that it need only be mentioned.

Hand Distance-Finder.—The naval range-finder now described is a development from a small instrument of 30 inches base, which was designed by the authors in 1888 as a field range-finder for infantry use. The first of these instruments which the authors constructed proved so far successful that it was the only single-observer instrument which passed the preliminary trials of infantry range-finders carried out by the War Office. For the final trials of the same series, a new instrument of 33 inches base was constructed at short notice. In this second instrument sextant mirrors were used for the end reflectors, in place of the reflecting prisms which had been used in the construction of the first instrument. The fixing of these mirrors securely enough and without deformation is a

great difficulty; and this led to a failure of the instrument so constructed. Through the experience gained in manufacturing the naval range-finder the authors have been able to construct a hand instrument of greatly improved design. For this instrument a base of 2 feet has been adopted, in order to secure great portability and handiness, so that the instrument may be used for a large variety of purposes. Among the purposes specially in view is the use of the instrument for navigation on the smaller sizes of ships, for yachting, for rapid surveying, more especially for military surveying and prospecting, and again for service as an artillery and infantry range-finder.

The optical details of this instrument, though of course of smaller dimensions, are practically identical with those of the naval range-finder. Mechanically the instrument differs from the latter in a number of important respects. The errors arising from bending of the instrument—under applied forces or differential heating—are much smaller in an instrument of shorter base; and this gives greater freedom of design. For simplicity and lightness the frame-piece supporting the optical parts of the instrument consists of a copper tube, $1\frac{1}{2}$ inch diameter and about 1–32nd inch thick; while the outer case is composed of a single brass tube, covered in some portions with leather.

The accuracy aimed at is one-third of that which the naval range-finder is designed to attain: namely 3 per cent. at 3,000 yards, 2 per cent. at 2,000 yards, and so on.

Small telemeters of this kind, weighing as they do only a few pounds, may conveniently be used in the hand, without any other support; but for special purposes they may be supported in various simple ways. Thus for military use the instrument may be supported on a rifle for a kneeling position, on a rifle with bayonet for a standing position, or on the bayonet alone for reclining. Again, for use on board ship or in the field, increased steadiness is obtained by attaching to the instrument a vertical rod, of adjustable length, the lower end of which may be supported on the belt or in the waistcoat pocket.

In this paper the authors have considered it advisable to confine themselves as far as possible to those portions of the subject which may seem to appeal more especially to Mechanical Engineers; and they have therefore not attempted to treat at all fully of the optical features of the instrument, which no doubt would prove of more special interest to physicists.

Discussion.

Professor ARCHIBALD BARR said that, had not the paper been prepared at the request of Professor Kennedy during his presidency, the authors might have had some misgivings as to this being the proper place in which to bring forward such a subject. At the same time it might not be altogether inappropriate that an institution of engineers should occasionally be asked to consider the design and construction of optical and other philosophical instruments. It would be remembered that it was by virtue of the knowledge and scientific habits of mind acquired in the design and construction of such instruments that both Smeaton, who might be looked upon as to a large extent the founder of modern civil engineering, and Watt, who certainly was the father of modern mechanical engineering, had been able to make such great advances towards what was now called engineering practice. The authors had not attempted to deal with the interesting subject of the use of the range-finder for naval or military tactics, or for active war purposes. This was perhaps not the place, and they certainly were not the persons, to speak upon that part of the subject with authority. They had attempted only to give the details of the instrument itself, in a way which they hoped might be of interest to the Members of the Institution.

The method of using the naval range-finder would be readily apprehended by inspection of the specimen exhibited, and its working would be further understood by examination of the internal portions, which were shown separately. When in use, the telescope portion of the instrument, described in the paper, was supported in

(Professor Barr.)

bearings attached to a swinging frame-work, which carried a balance weight. The frame-work rested on knife-edges attached to the cheeks of a metal box or tank, which in turn was supported upon a vertical spindle attached to a wooden pedestal. In this way the tank and instrument as a whole were free to be turned in azimuth upon the pedestal, while the swinging of the frame-work provided the motion in altitude necessary to counteract the rolling or pitching of the ship. In taking a range with the instrument, the observer leaned his body against the tank, grasped the handle of the rocking frame with his left hand, placed his right hand on the top of the milled head which worked the screw, and put his eyes to the eye-pieces. He then performed, as explained in the paper, the operation of finding the object with the left eye, making the observation with the right, and reading the scale with the left. Attached to the instrument at the eye-pieces there was an india-rubber face-piece, which had three important functions. First of all, as had been found by experience, the effect of gunnery was sometimes rather uncomfortable if no protection were given to the face of the observer; every time a gun went off, his nose received rather a smart blow from the shock which the discharge produced upon the range-finder. Secondly, the face-piece prevented stray light from getting access to the eyes of the observer. This gave the great advantage that, during the whole time he was working, his eyes were kept in darkness; and his vision thereby became much sharper than it would be if his eyes were not protected from extraneous light while observing, or if he had to remove his eyes from the instrument, and turn them to some other place for reading the scale. There was yet a third advantage, especially in the case of night observations: when but little light came through the right eye-piece, the eye did not find the aperture at all readily; but the face-piece at once put both eyes in the right position, and they were always ready to take an observation at once.

With regard to the accuracy or permanency of the range-finder, it had already been mentioned (page 54) that the instrument sometimes did not require adjustment for many months. They had since heard of one of the instruments, which had been sent by train

from Glasgow and used regularly on a small gunboat attached to one of the gunnery schools, and in fourteen months the adjustment had never been touched to the extent of a single second of angle. They had also heard of two range-finders which had met with somewhat serious accidents. On one occasion a ship's carpenter had screwed down two of the deck screws, and had left the others unscrewed. The ship was caught in a sea-way, and as she rolled the instrument fell right over, damaging the outer tube; but it had been used quite successfully for gunnery practice after that accident. Another instrument, which had lately been despatched from Portsmouth to one of the ships of the navy, had had its outer tube indented to a depth of half an inch. They did not know the condition of the interior further than that the captain of the ship reported that the instrument did not seem to have been impaired in regard to its accuracy.

Mr. ARNULF MALLOCK considered the authors of the paper were to be congratulated on the success they had attained, and also on having attained it largely by applying true kinematical principles to the construction of all the parts. One of the most important elements in good machine design he thought was to supply only the necessary and sufficient conditions for constraining the various parts to follow the paths desired or to lie in their intended positions. It was evident that the instrument now exhibited had been thoroughly thought out, and that in all the details this object had been kept constantly in view. The combination of the eye-piece prisms he much admired, having often found it useful to re-invert the image in a simple telescope by means of a direct-vision prism. In connection with the accuracy of the readings, the authors had not mentioned what was the magnifying power of their telescope.

Professor BARR said the magnifying power was from 25 to 30 times lineally; and the effective aperture was $1\frac{5}{8}$ inch diameter.

Mr. MALLOCK thought the defining power was estimated rather high in the statement that such a telescope could define an angle of

(Mr. Arnulf Mallock.)

one second. The defining power of a telescope depended upon the diameter of its object-glass; and roughly the angle which a telescope would define was the wave length of light divided by the diameter of the object-glass. With an inch object-glass it would define an angle of 1 in 50,000; and to make clearly apparent one second of arc would require a 4-inch object-glass. This was on the supposition that all the optical parts were perfect. No doubt when the observation consisted, as it here did, in bringing two lines into such a position that they appeared to form parts of one and the same continuous line, rather a smaller object-glass would be effective; but he should not expect in only one observation to be able to get the accuracy of one second of angle with certainty, unless employing an object-glass of something like three inches diameter. With the mean of several observations a better result might of course be obtained.

As to halving the field, it was represented in the paper (page 45) that the plan of dividing the image, and making the observation by bringing the halves together again, was better than having the entire field occupied by two complete images of the whole object and making these two images coincide. With the image halved as it here was, the observation was no doubt rendered much easier to a novice; but this method had the disadvantage that it confined the useful part of the field to the neighbourhood of the line of demarcation. That was of no consequence at all when the objects were large, or stretched right across the field from top to bottom; but for small rocks, boats, buoys, and such objects, there was a considerable difficulty in keeping the image in the neighbourhood where it must be in the field of view in order to be of any use at all. The angular aperture of the field had not been stated, and he should suppose it was small, probably not more than half a degree. If so, he imagined there would be considerable difficulty in keeping the object in the field at all; and this difficulty was increased by the fact that the object must not only be kept in the field, but must be kept in one part of the field. On the other hand, if the field was nearly covered by each of two complete images of the object, then wherever the object was in the field the observation could be proceeded with; and this he

considered was really a great advantage. Apart from this criticism however, he thought the authors had brought out what was certainly a remarkable and useful instrument.

The range-finder invented by himself, which had undergone its official trials at the same time as that of Professors Barr and Stroud, had given results which were nearly identical, as far as accuracy went, with those of the latter; and during the three years that it had been on one of the ships of the navy in the Mediterranean it had been found of great service. The principle embodied in that instrument consisted in such an arrangement of the optical parts that deformation or bending of the base did not affect the accuracy of the readings. On the other hand the leading feature in the Barr and Stroud range-finder was the careful protection of the base from any kind of deformation, whether by heat or by mechanical force. Each instrument had advantages and disadvantages which the other lacked; but in respect of giving the distance of an object which could be easily observed, both were equally successful.

Professor C. V. Boys joined the last speaker in congratulating the authors on the beautiful design of their instrument, and also in expressing his appreciation more especially of the kinematical relations, of which he believed the importance had not always been appreciated by practical men. If any one feature might be selected for praise beyond the rest, he should like to select the double-prism eye-piece, which he thought, looking at it purely as an experimental physicist, was a most beautiful device, and one which every scientific observer in a laboratory ought to be familiar with. It was a most beautiful way of obtaining, if desired, the focus of the dividing line and the focus of the two halves exactly together, so that the two images should be divided by a sharp line, instead of blending one into the other. The braced frame itself, delineated in Plates 3, 4, 5, and 10, was a most admirably matured contrivance, which alone would suffice to show what a broad distinction there was between what might be called the happy idea of such an instrument as this, and its practical realization in so perfect and beautiful a form as was here exhibited.

(Professor C. V. Boys.)

With reference to the defining power, he was aware that a lens or a mirror of about 4 inches aperture was capable of defining, in the astronomical sense, with an accuracy approaching one second of arc. But though this was undoubtedly true, and there was no way of getting round it by any ingenuity, because the limit was the consequence of the wave length of light and not of any fault of the instrument or of the instrument maker, it was nevertheless practicable as well as possible to read with such an instrument with a degree of accuracy considerably more minute than the limit of its dividing or separating power. It was true that with the 4-inch telescope, two stars which were $1\frac{1}{4}$ second apart could only just, if at all, be separated. If the telescope was less than 4 inches aperture, it was impossible to obtain clearly two separate discs for those two stars. On the other hand, if there were two stars any distance apart, the distance of which was being determined by a micrometer, it was possible to determine the distance of those two stars with a telescope of less than 4 inches aperture and with an accuracy more minute than one second; because, although the disc formed by each star, due to optical causes, subtended in a 4-inch telescope an angle slightly larger than one second, yet each disc could be bisected by a cross wire, and the distance between the two cross wires could be determined with an accuracy perhaps not so minute as one-tenth of a second, but somewhere between one-fourth and one-tenth. In his own experience he had made measurements down to about one second of arc with certainty with a small rectangular mirror only $0 \cdot 9 \times 0 \cdot 25$ inch aperture; and the accuracy of the apparatus he had employed had been confirmed by such high optical authorities as Professor Clifton and Professor Cornu of Paris. Readings correct to about one second of arc with a mirror of only an inch diameter were feasible and certain: that is to say, readings of the distances of two images, but by no possibility could they be separated if they were less than about $4\frac{1}{2}$ seconds apart. In connection with the possible defining power of a telescope or a mirror, it might be worth while to draw attention to the fact—even though it was not made use of in the instrument described, and perhaps it would not be feasible to make use of it—that a square telescope, if there

were such a thing, would define more accurately than a round telescope of the same diameter. Although there were not any square telescopes, the advantage of a square telescope could sometimes be obtained in a simple way with a circular mirror or telescope; if there was plenty of light and the instrument was optically perfect, it would be found that a slightly more accurate dividing power in one direction—say horizontally, which was all that had to be dealt with in range-finders—could be obtained by putting two bits of card or other opaque medium so as to blot out the top and bottom of the field and leave only the middle strip for use; the rectangular field so formed had then a slightly greater separating power horizontally than the open circular field from which it had been enclosed. It had indeed less separating power vertically, but this the observer did not care about in a range-finder.

One other point which called forth his admiration in the instrument exhibited was the beautiful way in which the authors had got over the great difficulties of magnifying the exceedingly small angle that constituted the especial feature of a range-finder: an angle represented by one second, or by only so many multiples of one second as were determined by the limit of the particular instrument. In each of the two instruments described of Adie and of the Astronomer Royal, what might be called a common method of the physical laboratory was made use of; but in each it necessarily failed, or at any rate worked under such great disadvantages that the slightest movements of the mirror or of the object-glass immediately produced a large effect upon the image. The accuracy with which those movements had to be effected was of the highest possible order. By making use of the refracting prism of small angle, the authors had arrived at a most beautiful and ingenious method of diminishing the effect of a given movement, and thus of magnifying the ease with which the adjustment might be made; the latter was the real practical point for the observer. There was one other method of producing precisely the same result, which had occurred to him when reading the paper over beforehand; and he noticed that the authors had already made use of it for what they called the halving adjustment (page 54). It had also been

(Professor C. V. Boys.)

brought into prominence by Professor Poynting, in his method of making a simple and perfect cathetometer. It consisted in the use of a pane of glass with flat parallel faces, through which the rays of light had to pass. As explained in the paper, if the glass was normal to the path of the rays coming from the object-glass of the telescope, the rays would go straight through; whereas, if it was inclined to their path, then the rays became slightly refracted downwards or upwards, and still went out parallel, and the image was thereby deflected downwards or upwards to an extent which was small in comparison with the angle through which the glass was inclined. By the use of such a pane, which might be made as thin as was desired—and the thinner it was, the more delicate was the adjustment effected by the same amount of angular movement of the pane—precisely the same optical result was obtained as by the use of the prism of small angle. The plain pane being already used for the halving adjustment, it had occurred to him to suggest that it would be possible to apply it with perhaps equal ease and convenience for the purpose of fulfilling the main adjustment and function of the whole instrument.

Professor A. G. Greenhill regarded the problem brought forward in the present paper as lying mid-way between the two extremes of a vast subject. At the one extreme was the question presented to astronomers of making use of the largest base available to them, namely the diameter of the earth or of her orbit—itself only a small base, even from the range-finding point of view—for determining the distance of such remote objects as the sun or fixed stars, of which the diurnal parallax ran down to $8\frac{3}{4}$ seconds for the sun, and the annual parallax to about one-third of a second for the nearest fixed stars. In connection with the authors' endeavour, in the design of the supports of their framework, to guard against a star appearing to be beyond infinity (page 51), perhaps it might be a comfort to them to know that astronomers occasionally met with stars of negative parallax. At the other extreme of the subject was the ordinary experience of daily life, in which the eyes were used as a range-finder, with the distance

between them for the fixed base; and here the time employed in range-finding had necessarily to be extremely short. The cricketer, for instance, had to estimate the range of the ball in something like one-tenth of a second, compared with which the ten seconds occupied with the naval range-finder appeared a long time. Ten seconds however he presumed would be considered a short time and a good achievement for military purposes, because for these extreme accuracy in the determination of the range was not a matter of so much importance compared with other details, such as rapidity; and for use on land he supposed a reduction in weight was a necessary qualification. The instrument now exhibited was obviously intended for use on board ship, where its weight was not so important. The hand instrument however, from the description given in the paper (page 57), appeared to satisfy all the requirements of a military range-finder. In the museum of a country town he once came across an instrument, bearing an inscription which stated that it had been invented for "determining the distance of an inaccessible object without going there—a problem declared impossible by mathematicians." So far however as the mathematics of the problem were concerned, it had been settled some two thousand years ago by Archimedes, as recorded in the "Poliorcetics" of Hero of Alexandria. But those ancients had not the advantage of the optical and practical improvements of the present century—advantages of which the authors of the paper had known so well how to make the best use.

Mr. Adam Hilger could see from his own experience in making the optical parts of instruments of this kind that there must have been a great deal of trouble in bringing the small prisms to such a state of perfection as to allow of such great precision in the adjustment of the instrument and in the observations made with it. Even at the present time there were some parts of the instrument which were exceedingly difficult to make, especially what was called the eye-piece prism combination (page 45), by which the two images were separated to such a sharp edge that the dividing line was almost invisible to the observer. Those surfaces being so small must

(Mr. Adam Hilger.)
be made as absolutely flat towards the edge in the angle as it was possible for them to be. It was almost an impossibility to get them absolutely close, and they had to be packed up at their edges with additional pieces of glass, in order to make a larger surface. The two pieces had to be brought so closely together, in cementing by means of Canada balsam, that there should not be the least deviation towards an incline or rounding between the two surfaces. On such a small scale the work was difficult, and there had been a great many failures. This was perhaps one of the most difficult parts of the whole instrument, though it did not appear to be so. In every respect all the optical parts were exceedingly difficult to make, and every surface of the whole of them was tested to a magnifying power of 500 times; because it was clear that, if there was the slightest error in any one part, it would get multiplied in the succeeding parts by reflection, and so would cause a diffused image to be presented to the observer. Achromatic object-glasses must of course be absolutely achromatic; and this result was obtained only through long experience and continuous changes of glasses of various refractive indices, crown and flint. A particular quality of glass was employed, which was obtained from Jena. It came nearest to freedom from chromatic aberration as well as from spherical aberration. The latter was not so difficult to get rid of, because the focus was made long as compared with the diameter of $1\frac{3}{4}$ to $1\frac{7}{8}$ inch. With a focus at 25 to 31 inches there was no particular difficulty; and with an object-glass of $1\frac{7}{8}$ inch diameter and a focus of only 29 inches, or even only 25 inches, absolute achromatism was obtained without the least spherical aberration. The magnifying power was 500 times, which was perhaps about as high as could be got, though he had made object-glasses of greater diameter, up to even $3\frac{1}{4}$ inches, which allowed a magnifying power of 500 times with a focal length of only $27\frac{1}{2}$ inches. It had formerly been supposed to be impossible to make an object-glass of so large a diameter with such a short focus; but as the chance had arisen of providing some of these glasses for astronomers, he had succeeded in doing it, the angle of the object-glass at the focus being $7\frac{1}{2}°$.

Mr. J. Hartley Wicksteed, Vice-President, asked why the authors had not been able to get a longer scale than six inches. The instrument appeared to be made $4\frac{1}{2}$ feet long, in order to get a base line long enough for the small angle; and this gave $2\frac{1}{4}$ feet from the centre to each end, which would appear to admit of a possible length of 2 feet for the scale. Why therefore should not the prism refracting the beam from the reflector be made with its faces more nearly parallel, and a scale be used of something like two feet length instead of only six inches?

Mr. Archibald P. Head was much impressed with the great optical and mechanical skill which had been evinced by the authors. The extreme accuracy of 1 per cent. at 3,000 yards he thought might possibly have been still more vividly realized, if a table had been given showing observed and verified distances. It was stated in page 36 that the alignment of the two images might be observed in any part of the field; and he should like to know what was the angle of the field, that is, what was the angle through which the instrument could be moved without losing sight of the object. In a heavy sea it seemed to him that there might be some difficulty in keeping the object in view. Rotation about a horizontal transverse axis he presumed did not affect the position of the image in the field, whereas rotation round a horizontal longitudinal axis or round a vertical axis did affect it. In this instrument there appeared to be two movements for correcting the two latter rotations, none being necessary for correcting the first.

The two-foot hand distance-finder was mentioned in page 58 as presenting great portability and handiness for a single-observer instrument; and it seemed to be really remarkably light and convenient. There were certain circumstances however under which a still lighter range-finder was required, as for instance in making rough preliminary surveys, where a great degree of accuracy was not required, where two observers were impossible, and where much luggage could not be carried. Two or three years ago he had been in search of an instrument for such a purpose, and Professor Barr had been so kind as to lend him one of the range-finders which

(Mr. Archibald P. Head.)

had been described at the British Association meeting in Leeds (Report 1890, page 499). It was an instrument for two observers, who had a cord stretched taut between them as a base line, from the extremities of which they took their observations simultaneously. That instrument he found remarkably accurate; but the need of two observers was a fatal objection in his case, and had finally led him to adopt an ordinary box-sextant of small size, only three inches diameter, by which with the aid of a vernier he could read an angle to within one minute. It fulfilled the three conditions of portability, speed of working, and only one observer. For the method which he adopted of using this instrument no claim of novelty could be urged, but it might be new to some persons. As shown in Fig. 41, Plate 12, the observer standing at A desired to measure the distance AO of an inaccessible point O. The instrument was first set to an angle of 90°, thus making an optical square. He then looked at O, and saw reflected upon O the image of some prominent object C to the right, such as a rock or a tree. If there was no such suitable object, he must shift his position A till he found one. Having done so, he deposited his knapsack or walking stick on the ground at A, and without using a base line he paced a base AB, not towards C, but away from it. The usual way with other range-finders was for the observer to walk towards C, leaving someone at A to keep him in line; but by the method described he walked away from C towards B, and when he had paced the base he faced about, and aligned himself with A and C, moving to the right or left if he found himself out of alignment. He then measured the angle ABO with the box sextant, and the tangent of that angle multiplied by the length of the base AB gave the required distance AO. The length of the base AB could be made anything convenient, according to the exigencies of the ground; and the aim should be to make it as nearly as possible proportional to the distance AO, so that the error might vary simply as the distance, and not as the square of the distance (page 37) as was the case in a range-finder of fixed base. By this method he found that with well defined objects at O and C an accuracy within 5 per cent. could be relied on.

Professor WILLIAM STROUD explained that the reason why a scale of only six inches length was employed (page 69) was because that length of scale was all that was wanted. A longer scale, while it would reduce the rapidity of working with the range-finder, would not enable the instrument to be read any more accurately. If it was wanted to obtain greater accuracy in connection with the instrument, it was the optical parts which would want improving. The present scale of only six inches length could be read at least five times as accurately as the instrument could be adjusted. There was therefore no object in making the scale reading any more accurate than it was at present, although of course the scale could be lengthened out to a greater extent if there were anything to be gained thereby.

The range-finders made some years ago and exhibited at the British Association meeting in 1890 in connection with a sextant or optical square (page 70) had not been dealt with in the present paper, in which it had been considered quite sufficient to treat only of single-observer range-finders. The method of range-finding described by Mr. Head would not be of any avail for determining distances when either the object or the observer was in motion; and this the naval range-finder was designed to accomplish.

The present instrument had been spoken of as originating in a happy idea (page 63); and roughly speaking it might indeed be said that the whole of the original design for the range-finder had been schemed in about three weeks; but it had taken seven or eight years really to work out all the practical details of the instrument. A good deal of work had been done in connection with the eye-piece prism combination; and it was highly gratifying to receive Professor Boys' assurance of the value of this arrangement. Some six or eight different eye-piece prism combinations had been made at different times in connection with the range-finder; but these had not been referred to in the paper, because it was thought they would be of interest to physicists rather than to engineers.

With reference to the suggestion (page 66) to use a thin parallel plate of glass for producing the small optical shift of image, that method appeared to him to possess no advantage over the travelling prism, but several disadvantages. A thin plate would

(Professor William Stroud.)
indeed be of no avail, owing to its extremely limited range of adjustment; in order to produce the requisite shift of image, a plate of glass at least half an inch thick would be required. Taking a plate of glass half an inch thick, and rotating it 30° on each side of the mean position, the motion so obtained of the image would be equivalent to what was obtained at present with the prism; but the position of the focal plane would be altered by no less than 1–30th of an inch in its extreme position—an amount quite inadmissible. The lack of definition too would be highly objectionable. Moreover gearing would have to be introduced between the plate and the scale, in order to magnify the angular motion of the plate. It was true that a plate was used in this way for effecting the halving adjustment (page 54); but in this case the range of adjustment to be covered was comparatively small, and the extent of motion had not to be recorded. Again, the device of a refracting prism which had been adopted gave a scale of equal angles; whereas the parallel plate would give a scale of angles approximately but not rigidly equal, so that the construction of the scale would be much more difficult. Further, it did not appear that it would be easy to retain the present method of reading the scale by the left eye, upon which depended much of the ease and rapidity that could be attained in the use of the instrument. On every account he considered the parallel plate was inferior to the travelling prism for a convergent beam of light. Outside the telescope, in an approximately parallel beam of light, he quite appreciated the merits of the parallel plate, which had been employed many years ago by Helmholtz in his ophthalmometer. It might be interesting also to note that James Watt had invented a telemeter about 1770, in which one half of a prism of small angle was angled relatively to the other half, in order to produce a different amount of deviation; and by its inclination, as shown on a divided sector, to indicate the distance of a rod carrying indices or targets at a known distance apart.

With reference to the accuracy of the instrument, as a matter of fact it was found quite feasible, when merely taking what might be called "snap shots," to get to an accuracy of one second. It was

further quite feasible, if the range-finder was treated as a scientific instrument in the ordinary way in which a laboratory instrument would be treated—namely by taking readings above and below the correct value—to get to an accuracy as minute as half a second of arc, or even less, with the present magnifying power of about twenty-five times lineally. [See table, page 75.]

The horizontal angular aperture of the field in the telescope (page 69) amounted to 5–8ths of an inch at a distance of $25\frac{1}{2}$ inches, or nearly $1\frac{1}{2}$ degree, or 5 in 204, while the vertical aperture was about two-thirds of a degree (page 62).

The paper he considered had been generously dealt with by Mr. Mallock, who had not referred at all fully to his own work in connection with range-finding. He had been the most serious competitor they had had to encounter in the range-finder trials; and so far as accuracy was concerned, he understood that there was not much to choose between the Mallock telemeter and the Barr and Stroud instrument tried against it. The latter had a base length of 5 feet, as against 8 feet he believed in Mr. Mallock's range-finder. That first Barr and Stroud instrument had not the system of eye-piece prisms described in the paper, but a much inferior arrangement; nor had it the copper frame-piece, or other details of the instrument now described. It was in consequence subject to errors from differential heating and other causes. They regretted that they had failed to get any particulars of the Mallock naval range-finder, as they had wished to refer to it in the paper. Perhaps on some future occasion Mr. Mallock would offer to the Institution a description of his own range-finder, of which the leading principle was of much interest and value.

As to the advantage of forming two complete overlapping images (page 62), so that observation could be made in any part of the field, their own experience was that satisfactory observations could not be made unless the images in the field were under good control. The image of a small object must be fairly stationary for the eye to observe at all satisfactorily; and given that a fairly stationary image was necessary, he saw no objection to bringing it to a special part of the field for examination. Moreover the object most

(Professor William Stroud.)

commonly observed upon was a ship's mast or funnel; and in that case a considerable vertical motion of the image could take place without its ceasing to cross the horizontal separating line. In regard to small rocks, boats, buoys, and such objects (page 62), which had sometimes to be observed, the astigmatiser was of great advantage, inasmuch as it gave long vertical streaks upon which to work. In any case experiments had convinced them that the method of overlapping images was greatly inferior to the method of alignment between separate images.

Last of all he wished to refer to the indomitable energy and perseverance of his colleague, Professor Barr. Had it not been for these, he should himself have thrown up the whole question three or four years ago.

Professor BARR said that, with regard to the difficulty of using the range-finder at sea, he had had some experience himself, but he had not had experience in rough weather. During the last naval manœuvres, through the kindness of Captain Grenfell, their assistant Mr. Jackson (who had not had any previous experience of the instrument at sea, though he had had a good deal of experience with it on land) had been privileged to go with a range-finder on H.M.S. "Benbow." The ship had encountered fairly rough weather. For example, on one occasion she pitched to such an extent that the tarpaulin covering the breech of the 110-ton bow gun was unshipped by a sea taken over the bow, the angle-iron fixings of the cover being carried away. Under circumstances such as these Mr. Jackson stated that he had practically had no difficulty whatever in using the instrument. Similar reports had been received from naval officers who had had experience of the working of the range-finder at sea. In calm weather certainly no one had any difficulty in using the instrument after two or three minutes' trial. At the present time hundreds of observations of one kind or another were being made with these instruments. Unfortunately not many were of the kind referred to by Mr. Head (page 69), in which distances observed and directly measured could be compared. One reason was that except under specially favourable circumstances in regard to the

nature of the intervening ground, it was exceedingly difficult to determine the distances of objects by any ordinary means as accurately as the range-finder itself would determine them.

The accompanying table recorded a few observations taken in adjusting instrument No. 35 by observing upon known distances. These observations were not selected as the best that had been obtained, but as fairly representing the accuracy with which the instrument could be worked under good conditions as regarded

Observations with Range-Finder No. 35.

Set No.	HOUSE. Reading in Yards.	HOUSE. Corresponding Angle. Mins.	HOUSE. Corresponding Angle. Secs.	CHIMNEY. Reading in Yards.	CHIMNEY. Corresponding Angle. Mins.	CHIMNEY. Corresponding Angle. Secs.	SPIRE. Reading in Yards.	SPIRE. Corresponding Angle. Mins.	SPIRE. Corresponding Angle. Secs.
1	325·1 325·3 325·1 325·3 325·1	15 15 15 15 15	51·7 51·1 51·7 51·1 51·7	1930 1940 1950 1940 1950	2 2 2 2 2	40·3 39·5 38·7 39·5 38·7	Spire	invisible.	
Mean	325·2	15	51·4	1942	2	39·3			
2	325·1 325·3 325·4 325·3 325·3	15 15 15 15 15	51·7 51·1 50·8 51·1 51·1	1950 1950 1950 1950 1950	2 2 2 2 2	38·7 38·7 38·7 38·7 38·7	Spire	invisible.	
Mean	325·3	15	51·1	1950	2	38·7			
3	326·1 326·0 325·9 325·9 326·1	15 15 15 15 15	48·8 49·1 49·4 49·4 48·8	1980 1970 1970 1980 1970	2 2 2 2 2	36·2 37·0 37·0 36·2 37·0	6050 5950 5950	0 0 0	51·1 52·0 52·0
Mean	326·0	15	49·1	1974	2	36·7	5983	0	51·7
4				1965 1970 1985 1975	2 2 2 2	37·4 37·0 35·8 36·6	5950	0	52·0
Mean				1974	2	36·7	5950	0	52·0

(Professor Archibald Barr.)

steadiness of platform &c. They had not been made specially, but were quoted from the laboratory record book. The objects observed were:—a house at 326·1 yards distance by direct measurement; a chimney believed to be at 1,975 yards from observations with other range-finders; Renfrew church spire, measured on ordnance maps as 5,930 yards. The house and spire were used as data, from which to determine the constants for the scales of the instruments. The angles recorded were the angles subtended by the base length at the distances read by the instrument. The observations in sets Nos. 1 and 2 were taken when the instrument was not in adjustment, and for the purpose of adjusting it. In set No. 1 the chimney was very hazy with driving rain; in set No. 2, taken an hour later, it was much clearer. Sets Nos. 3 and 4 were taken after the instrument had been adjusted to 326 yards on the house; set No. 3 was taken by one observer, and No. 4 by another; in No. 3 the spire was very faint. These and many other such sets of observations he thought bore out the statement in the paper, that under favourable conditions the range-finder was able to work to an accuracy within one second of angle.

With what had been said by Mr. Mallock on the physical limitations of the resolving power of telescopes (page 62), he could not but agree. Furthermore, physiologists stated that the retinal cones, which seemed to be the centres of independent sensations, subtended visual angles of about one minute, and that this angle consequently limited the resolving power of the eye for spots of light; and this was confirmed by experiment. Thus it was stated by Professor Foster ("Text Book of Physiology," fifth edition, part iv, page 1219):—"In most people two stars . . . . appear to become one when the angle subtended by the distance between them becomes less than sixty seconds or one minute. And similar measurements are obtained when other images are made to fall on the fovea, such as those of parallel white streaks on a black ground, or black streaks on a white ground. In the case of an acute and trained observer, this minimum distance may be diminished to fifty seconds." It would therefore appear that, independently of the limitations of telescopic definition referred to by Mr. Mallock, a

magnifying power of at least sixty diameters was necessary in order that two stars or two overlapping lines subtending an angle of one second might be capable of being resolved. But careful tests made by themselves at different times and with different observers, on the accuracy of observing the alignment of two lines in the manner illustrated in Fig. 10, Plate 6, had produced results which were somewhat surprising in view of these physiological limitations of visual power, and showed clearly that the limits of resolving power applicable to spots or overlapping lines did not at all apply to the method of alignment adopted in the range-finder. Thus two students, not specially trained in scientific observations, could by the naked eye distinguish with certainty a shift of 1–50th of an inch at a distance of 20 feet when black lines on a white ground were used. This represented a visual angle of $\frac{1}{3 \cdot 5}$ minute. Another observer had been invariably correct in detecting shifts of $\frac{1}{3 \cdot 6}$ minute with the same marks. With white lines on a black ground the same students could detect shifts of less than $\frac{1}{4}$ minute. These experiments had been made by means of cards, upon which were drawn vertical lines out of correct alignment, as in Fig. 10; and the observer had been asked to say whether the upper line was to the right or to the left of the lower. The authors had made a number of experiments, referred to in page 45 of the paper, on the accuracy with which separated and overlapping images could be adjusted into alignment or coincidence. These experiments showed that, while overlapping images gave just such results as would be expected from the construction of the eye itself, separated images could be aligned with an accuracy several times as great. One reason for this had been referred to by Professor Boys (page 64). It would be evident that two images with edges considerably but similarly blurred could be balanced, when separated as in Fig. 10; whereas with overlapping images, as in Fig. 25, Plate 8, the blurring or shading of the edges of the two images would merge into each other, and could not be distinguished from a single blurred image. Over and above the greater accuracy, there was a further great practical advantage in the separated images, namely that, when a want of alignment was observed, it was always known instantly

(Professor Archibald Barr.)

which way to move the working head; whereas with overlapping images it was not known which image was to the right and which to the left.

An examination of the engraved scale of six inches length, which was exhibited separately, would give some further idea as to the delicacy of the instrument. Between the point which represented infinity, and the other extremity of the scale which represented the minimum distance of 250 yards, there were some four hundred graduations, and some of them were so close that they could scarcely be distinguished at all without a magnifying glass. As stated in the paper (page 37), the whole of these graduations were virtually contained within an angle of only one-third of a degree.

The PRESIDENT was sure the members would accord to Professors Barr and Stroud a hearty vote of thanks for their most interesting and able paper.

CALCULATION OF HORSE-POWER FOR MARINE PROPULSION.

BY LT.-COLONEL THOMAS ENGLISH.

The author desires to call attention to a method of calculating, from the results of a single sea-trial of one ship, the horse-power necessary to propel another ship, of the same type, at any required speed. By this method it becomes practicable, with the ordinary appliances of a ship-yard, to approximate closely to results which could otherwise be obtained only by the use of the refined apparatus of a model tank.

It is generally agreed that the most accurate method at present known of estimating the resistance of a ship at any particular speed is that worked out by the late Mr. William Froude, which consists in separating the part of the resistance due to skin friction from the part due to wave and eddy making. The skin friction varies with the length, area, and nature of the wetted surface, and with a power of the speed less than the square, in such a way that it can be readily tabulated, whilst it is practically independent of the displacement. The residuary resistance caused by wave and eddy making cannot be so dealt with, and at present can be satisfactorily ascertained only by trial, either of an actual ship at sea, or of a model in a tank. When this is done, the residuary resistance at one other corresponding speed can be calculated for any ship or model of the same shape, but of different displacement, according to Froude's law of comparison. This law is equivalent to the statement that, if the speeds of a model and of the ship which it represents are made proportional to the sixth roots of their respective displacements, the residuary resistances at these corresponding speeds will be proportional to the displacements.

Principle.—The method about to be described is based upon the self-evident proposition that it will always be possible to make two models on such scales that, according to Froude's law, the same absolute speed will for one of the models correspond with that of a ship which has been tried at sea, and for the other with that desired for a proposed ship. The actual resistance of the model of the ship already tried at sea can be calculated by Froude's method; and if the ratio of the total resistances of the two models at the same speed is found by trial, the actual resistance of the second model will be known. From this, also by Froude's method, the resistance of the proposed ship at the desired speed can be calculated. The details of the calculation are as follows. If the total resistance of a ship of known displacement D_1 at any known speed V_1 be ascertained by trial, and it is desired to find the total resistance of a second ship, on either the same or different lines, of displacement D_2 and at a speed V_2: let models of the two ships be made, of displacements d_1 and d_2 such that—

$$\frac{d_1}{d_2} = \frac{D_1}{D_2} \times \left(\frac{V_2}{V_1}\right)^6$$

and let the following be corresponding quantities for the ships and models:—

Wave Resistance.	*Skin Resistance.*	*Displacement.*	*Speed.*
W_1	S_1	D_1	V_1
W_2	S_2	D_2	V_2
w_1	s_1	d_1	$V_1 \left(\frac{d_1}{D_1}\right)^{\frac{1}{6}}$
w_2	s_2	$d_1 \times \frac{D_2}{D_1} \left(\frac{V_1}{V_2}\right)^6 = d_2$	$V_1 \left(\frac{d_1}{D_1}\right)^{\frac{1}{6}}$

Also let n be the ratio of the total resistances of the two models at the same speed $V_1 \left(\frac{d_1}{D_1}\right)^{\frac{1}{6}}$

Then $$w_1 = W_1 \times \frac{d_1}{D_1}$$

$$w_2 + s_2 = n\,(w_1 + s_1)$$

$$w_2 = n\,W_1 \times \frac{d_1}{D_1} + ns_1 - s_2$$

$$W_2 = w_2 \times \frac{D_2}{d_1 \times \frac{D_2}{D_1}\left(\frac{V_1}{V_2}\right)^6}$$
$$= \left(\frac{V_2}{V_1}\right)^6 \times \left\{nW_1 + \frac{D_1}{d_1}(ns_1 - s_2)\right\}$$

and the total resistance of the second ship of displacement D_2 at the speed V_2 will be represented by the following expression—

$$S_2 + \left(\frac{V_2}{V_1}\right)^6 \times \left\{nW_1 + \frac{D_1}{d_1}(ns_1 - s_2)\right\}$$

in which all the terms are known, and from which the required horse-power can be obtained.

The four values of skin resistance—S_1, S_2, s_1, s_2—must be calculated from tables of skin resistance. The value of the wave resistance W_1 for the first ship with displacement D_1 must be deduced from the indicated horse-power required to propel her at the particular speed V_1, using an appropriate co-efficient for the ratio $\frac{\text{thrust horse-power}}{\text{indicated horse-power}}$.

The value of n, that is, the ratio of the total resistances of the two models at the same speed, is obtained by attaching the models to the two arms of a horizontal lever, and towing from the fulcrum at that speed, namely $V_1 \times \left(\frac{d_1}{D_1}\right)^{\frac{1}{6}}$; the relative lengths of the lever arms being adjusted by trial, until the models tow steadily abreast. As this value of the ratio n can be obtained without knowing the actual resistance of each model, the delicate dynamometrical apparatus which forms one of the chief features of a model tank may be dispensed with, and the final result is arrived at by simple means.

Apparatus.—In Figs. 3 and 4, Plate 14, is shown an apparatus which has been found to answer well for this purpose. It consists of a small electro motor, furnished with a resistance coil, and running at from 900 to 1,000 revolutions per minute. At this speed the motor is adjusted to give off about one-sixth of a brake horse-power, or a pull of about 8·4 lbs. through 631 feet per minute on an endless piano wire No. 18 music-wire gauge or 0·036 inch thick, stretched over two pulleys PP, $11\frac{5}{8}$ inches

diameter, on horizontal axes about 350 feet apart. One of these pulleys is connected with the motor shaft by belting on a pair of driving pulleys; and the other is arranged to stretch the wire by means of a weight W, until the sag does not exceed three or four inches. The pulleys are supported by staging, so that the wire between them is suspended horizontally over the surface of any convenient sheet of water, such as a partially filled dry-dock, not less than five or six feet deep, as shown in Figs. 1 and 2, Plate 13.

The towing frame is composed of steel bicycle tube, and consists of two similar and parallel transverse levers LL, each 60 inches between centres, pivoted at their ends to the decks of the models M, so that the latter will always be parallel to each other. The levers are graduated into 1,000 divisions of nearly 1–16th inch each, and are attached by short collars, which can be clamped at any required graduation, to pivots at the ends of a horizontal bar B, which is of the same length, 4 feet, as the distance between the pivots on the deck of each model. The details of the towing frame are shown in Figs. 5 to 14, Plate 15. The bar B carries a vertical spindle S, Fig. 6, to which the lower wire is connected by a ring R that can travel up and down the spindle, and thus allow for the sag of the wire. Vertical slotted guides G embrace the wire at both ends of the bar, and thus keep the bar, and therefore the models, in a straight course.

The models, the larger of which is about ten feet long, are made of yellow pine, of ordinary ship-yard workmanship, and are ballasted with lead to the required draught and trim; they are well painted, rubbed down, and varnished. Loose diagonal cords connecting the models serve as stops to prevent them from coming close together when one lags behind the other. The levers are always clamped at the same graduation on each; and this is varied by trial, until the models tow abreast at the required speed. It is found that a variation of 1–8th inch, or 0·002 of the total length of the lever, produces a sensible effect upon the result; and that the requisite speed can readily be obtained within limits of ± 0·02 knot per hour. The models are brought to rest by disconnecting the motor switch and applying a brake, and after a run are towed astern to the starting platform by crossing the belt on the driving pulleys.

Example.—The following example will show the application of this method to determine the horse-power required for a torpedo destroyer of 300 tons displacement and 30 knots speed, on the lines of H.M.S. "Janus" and "Lightning," built by Palmer's Company, Jarrow, of 247 tons displacement and 27·85 knots speed on trial.

The linear dimensions will be increased as $\left(\frac{D_2}{D_1}\right)^{\frac{1}{3}}$ or as $\left(\frac{300}{247}\right)^{\frac{1}{3}}$ or as $\frac{1 \cdot 067}{1}$. The corresponding speed $V_1 \left(\frac{d_1}{D_1}\right)^{\frac{1}{6}}$ of a model of the "Janus" on 1–20th scale will be $\frac{27 \cdot 85}{\sqrt{20}} = 6 \cdot 23$ knots. The scale of a model of the proposed ship, for which 6·23 knots is the corresponding speed to 30 knots for the full-sized ship, is

$$\left(\frac{6 \cdot 23}{30}\right)^2 = \frac{1}{23 \cdot 21}.$$

The wetted surface of the "Janus" is		3,796 square feet.
" " "	proposed ship is	$3{,}796 \times 1 \cdot 067^2 = 4{,}321$.
" " "	$\frac{1}{20}$ scale model is	$3{,}796 \times \frac{1}{20^2} = 9 \cdot 49$.
" " "	$\frac{1}{23 \cdot 21}$ scale model is	$4{,}321 \times \frac{1}{23 \cdot 21^2} = 8 \cdot 02$.

Hence from tables, the skin resistance—S_1 of the "Janus," S_2 of the proposed ship, s_1 of the model of the "Janus," and s_2 of the model of the proposed ship—will be

$$S_1 = 0 \cdot 0094 \times 3{,}796 \times 27 \cdot 85^{1 \cdot 83} = 15{,}720 \text{ lbs.}$$
$$S_2 = 0 \cdot 0094 \times 4{,}321 \times 30 \cdot 00^{1 \cdot 83} = 20{,}500 \text{ ,,}$$
$$s_1 = 0 \cdot 01124 \times 9 \cdot 49 \times 6 \cdot 23^{1 \cdot 85} = 3 \cdot 15 \text{ ,,}$$
$$s_2 = 0 \cdot 01124 \times 8 \cdot 02 \times 6 \cdot 23^{1 \cdot 85} = 2 \cdot 66 \text{ ,,}$$

Indicated horse-power of "Janus" at	27·8	knots	= 3,840.
" " " "Lightning" at	27·9	"	= 3,990.
Mean indicated horse-power at	27·85	"	= 3,915.

If the co-efficient $\frac{\text{thrust horse-power}}{\text{indicated horse-power}}$ be taken as 0·6, the mean thrust horse-power = 2,349.

Hence the wave resistance and the skin resistance of the "Janus" together amount to

$$W_1 + S_1 = \frac{2{,}349 \times 33{,}000 \times 60}{27 \cdot 85 \times 6{,}080} = 27{,}467 \text{ lbs.};$$

and the wave resistance alone is

$$W_1 = 27{,}467 - 15{,}720 = 11{,}747 \text{ lbs.}$$

It is found on trial that the ratio of the total resistances of the models is $n = \frac{w_2 + s_2}{w_1 + s_1} = 0 \cdot 811$. Hence the total resistance of the proposed ship is

$$\begin{aligned} W_2 + S_2 &= S_2 + \left(\frac{V_2}{V_1}\right)^6 \times \left\{ n W_1 + \frac{D_1}{d_1} (n s_1 - s_2) \right\} \\ &= 20{,}500 + 1 \cdot 077^6 \times \{0 \cdot 811 \times 11{,}747 + \\ &\qquad 8{,}000\,(0 \cdot 811 \times 3 \cdot 15 - 2 \cdot 66)\} \\ &= 34{,}000 \text{ lbs.} \end{aligned}$$

The thrust horse-power is $\frac{34{,}000 \times 6{,}080 \times 30}{33{,}000 \times 60} = 3{,}132$ H.P.

The indicated horse-power required is $\frac{3{,}132}{0 \cdot 6} = 5{,}220$ H.P.

So long as the ratio $\frac{\text{thrust horse-power}}{\text{indicated horse-power}}$ remains the same for both ships, its assumed value may be varied between wide limits. Variation in the speed of towing, or in the condition of the surfaces, provided the surfaces are the same for both models or for both ships, may also take place without materially affecting the result.

In Figs. 15 and 16, Plate 16, the method of calculation is shown in the form of diagrams, in which abscissæ represent speeds in knots, ordinates in Fig. 15 represent skin resistances in pounds, and ordinates in Fig. 16 represent wave resistances in pounds. The points indicated in the curves for the "Janus" represent the results of a series of speed trials at approximately the same displacement. The curves of resistances of models show the results when the speed varies with the sixth root of the displacement, whilst the same lines are retained throughout. If the diagrams were carried back far enough to show the actual speed of 6·23 knots, at which the models were towed, the ordinates representing their resistances would not be distinguishable on any reasonable scale; but the

ordinates at any point within the limits of the diagrams will equally represent the resistances of an assumed pair of models, increased in displacement as the sixth power of the speed. In Fig. 17 the full lines show the wave resistances calculated for various displacements, from the progressive speed-trials of the "Janus." The dotted curves AA and BB of corresponding resistances of models, passing through the ends of the "Janus" speed-trial curves, show for the various displacements the limits of speed, beyond which in this case the method of progressive speed-trials becomes inapplicable: for example, at about 28·7 knots for 300 tons displacement.

If by means of a tank experiment the total wave and skin resistance, $w_1 + s_1$, of a floating body of any convenient shape and size, towed at a known speed v_1, be ascertained, this resistance may afterwards be used as a standard for obtaining by the apparatus described the comparative resistance of a model made to the proper scale $\left(\frac{v_1}{V_2}\right)^2$ of any proposed ship whose speed is desired to be V_2. Then the wave resistance of the proposed ship will be

$$W_2 = w_2 \times \left(\frac{V_2}{v_1}\right)^6 = \left(\frac{V_2}{v_1}\right)^6 \left\{n\ (w_1 + s_1) - s_2\right\}$$

and the total resistance of the proposed ship will be

$$S_2 + \left(\frac{V_2}{v_1}\right)^6 \left\{n\ (w_1 + s_1) - s_2\right\}.$$

It is obvious however that the calculation of indicated horse-power from this result is much more dependent than it is in the method first described upon the accurate estimation of the ratio $\frac{\text{thrust horse-power}}{\text{indicated horse-power}}$, and of the speed v_1 of the model, and upon the condition of the surfaces.

Discussion.

Mr. R. Edmund Froude wrote that the method of experiment proposed by the author struck him as a highly ingenious way of obtaining a horse-power estimate for a new form of hull from an experiment on a model, without the aid of very elaborate apparatus. The special advantage of the expedient of towing two models from opposite ends of the same steel-yard, so as to measure simply their relative resistances, seemed to him to lie in the circumstance that two of the most troublesome elements of variation in the measure of resistance of an individual model were approximately common to both models, and so scarcely entered into the measure obtained. These elements were: first, the forces of acceleration or retardation due to slight unevennesses in the speed; and second, the variation of mean resistance due to variation of mean speed. In so far as this latter characteristic was common to all forms of hull, as it was to a great extent, the measure of speed in Colonel English's method needed less exactness.

It occurred to him that this method of experimenting might be made more comprehensive in result, by using, for what might be termed the counter-model, not a model of an existing ship of known horse-power at some particular speed, but a model of extreme length and small cross-section and very fine lines, of which the "residuary resistance" should be small and capable of estimation with fair accuracy. This condition might be easily fulfilled, he thought, if the speeds of experiment were no greater than would be required in testing a model of a large ship, such as a fast war cruiser or passenger liner; though it could scarcely be fulfilled for the higher speeds necessary in testing a model of a "destroyer" or a torpedo-boat.

By way of criticism of detail, he was inclined to think that for models 10 feet long a distance of only 4 feet apart was scarcely sufficient to ensure that the disturbance produced by the one model should in no way affect the resistance of the other.

Professor Archibald Barr said that one point noticed by Mr. Froude had also occurred to himself, namely the distance between the two models towed abreast. He should like to know what happened when the resistances of the two models, as represented by the leverages, were not exactly equal. It appeared to him that there would be more or less instability in the lever arrangement, and that the models would immediately become close together, unless means were taken to give some little stability to the arrangement, so that the lever should under all circumstances keep roughly at right angles to the pulling wire. The application of this principle was of much interest to himself, because a number of years ago he had partially designed, or at least suggested, an apparatus upon the same principle for measuring wind pressures on surfaces of different forms and presented at different angles to the wind.

Another question he wished to ask was whether or not there was any advantage in regard to the cost of production of these wooden models over the models made of wax, which had hitherto been used for the purpose of such experiments.

Mr. Leslie S. Robinson asked whether it was expected to get a speed of 30 knots on the 5,220 horse-power arrived at in the paper by the calculations derived from the experiments on the models. Most marine engineers, he believed, were reckoning upon nearly 6,000 horse-power as necessary for a ship of 300 tons displacement and 30 knots speed.

Lt.-Colonel English replied that the distance apart of the models was arranged after observation of the waves caused by the actual ship at her trial. The waves were measured as spreading out a certain distance laterally at the stern of the ship, and the models were adjusted at a corresponding distance apart, so that throughout the length of the models the waves made by either were clear of the other model. It should be borne in mind that, in Mr. Froude's method of towing a model at a speed corresponding with that of the ship from which the model was made, a model was thereby produced of the actual wave-surface made by the ship herself at full speed, the waves

(Lt.-Colonel English.)
made by the model corresponding in all respects with those made by the ship, and spreading laterally at the same angles, so far as could be seen. It was extremely beautiful to see how nearly in that sort of experiment the model waves corresponded with the actual waves produced by the ship. The photograph exhibited of the "Janus" at full speed showed what was the general appearance of the waves she produced; and the waves produced by the model were as nearly as possible a true copy in miniature.

When the moments of the resistances of the models to towing were unequal, it had not been found in the trials made that there was any difficulty arising from the models closing together. As mentioned in the paper, loose diagonal cords were put to serve as a stop for preventing this; these cords were not shown in the drawings, but it would be readily understood that a diagonal cord from model to model, or from either model to any part of the towing frame, would keep them from coming too close together. For the particular trial recorded in the paper (pages 83–84) eleven runs had been made, and after the first three the models were almost exactly abreast the whole time. The difference was extremely slight; sometimes both models led in turn. When the levers had been properly adjusted, the speeds of the two models were perfectly equal, and the models remained square throughout their whole course.

With regard to the employment of wooden models instead of those made of wax, he was afraid the ordinary ship-yard model-maker would be considerably puzzled to make a model in paraffin. That was the only reason why wood had been adopted.

As to the horse-power calculated, he believed that a ship built as specified on the lines of the "Janus," with equal freedom from vibration, and of 300 tons displacement, would certainly attain 30 knots with the 5,220 indicated horse-power calculated from the experiment.

In regard to Mr. Froude's remarks (page 86), he thought that, as mentioned in the last paragraph of the paper, a difficulty lay in the way of using a counter-model of any shape which did not represent an existing ship of known horse-power, through the uncertainty in estimating the ratio $\frac{\text{thrust horse-power}}{\text{indicated horse-power}}$ for the

proposed ship. This uncertainty was in great measure avoided when the counter-model represented a ship of known horse-power: for example, if the ratio $\frac{\text{thrust horse-power}}{\text{indicated horse-power}}$ were called C_1 for the "Janus," and C_2 for the proposed ship, it could easily be deduced from the figures given that the expression for the indicated horse-power of the proposed ship would be $\frac{5{,}335\ C_1 - 69}{C_2}$. The result was thus practically dependent only on the proportion which C_2 bore to C_1, and not on the actual value of C_2. Hence for ships and engines of the same type, the most probable errors—such as assuming too large or too small a value for both C_1 and C_2—would partially or entirely neutralize each other.

The PRESIDENT was sure the members would desire to give Lt.-Colonel English a hearty vote of thanks for his interesting paper.

MEMOIRS.

JAMES ABERNETHY was born in Aberdeen on 12th June 1814. At an early age he became an assistant to his father, Mr. George Abernethy, who was then resident engineer at the London Docks, under Mr. Henry Robinson Palmer. In 1839 he went to Goole Docks as assistant engineer to Mr. George Leather of Leeds. From there he moved to the Aire and Calder Canal; and afterwards to the North Midland Railway between Wakefield and Leeds. In 1840 he became resident engineer at Aberdeen Harbour, where in one year by systematic dredging he improved the tidal flow so much that the depth of water on the bar was increased from 2 feet to 5 feet at low water. In 1844 at the age of twenty-nine he was entrusted as engineer-in-chief with the design and construction of the Aberdeen Docks, and from that period he was continuously engaged in connection with many harbours and ports in the United Kingdom and abroad. Among a few of such works, which bear testimony to his eminence as a hydraulic engineer, may be mentioned Swansea Harbour, 1847 and 1881; Birkenhead Docks, 1851–58; Silloth Docks, 1856–59; Newport Docks, Monmouthshire, 1856 and 1876; Falmouth Harbour 1858–1861; Alexandra Dock, Hull, 1881; and Bute Docks, Cardiff, 1887. He was also consulting engineer to the Manchester Ship Canal, 1888–92, Sir E. Leader Williams being engineer-in-chief. In 1854 he took an office in Parliament Street, Westminster, permanently establishing himself in London; and in 1892 he took his two elder sons into partnership. He served on the Royal Commission for Metropolitan Sewage Discharge in 1882; and again on that for Irish Public Works in 1886. From the King of the Belgians he received the Order of Commander of Leopold, in recognition of his services as a member of a jury appointed to report upon the construction of harbours on sandy coasts. For many years he had been a justice of the peace for Kent and Middlesex. The last work on which he was engaged was that of deepening and

extending the harbour of Fraserburgh in Scotland, with which he first became professionally connected in 1856. His death took place at his residence at Kingsgate near Broadstairs on 11th March 1896, in his eighty-second year. He became a Member of this Institution in 1874; he joined the Institution of Civil Engineers in 1844, and became President in 1881; and he was also a Fellow of the Royal Society of Edinburgh.

William Alexander Adams was born on 26th August 1821 at Quintero, near Valparaiso in Chili, whither his father William Bridges Adams, well known as an engineer and inventor, had gone for his health. In 1826 they came to London, where at the age of fifteen he commenced his practical education in the carriage works of his father and uncle in Drury Lane. His natural mechanical talent and perseverance were early shown by his making at the age of sixteen a model of an oscillating-cylinder engine. In 1843 the Fairfield Works, Bow, were built by his father and uncle, by whom he was taken into partnership in the business of general carriage builders for road and railway. In 1846 he became manager to Messrs. Fox, Henderson and Co., London Works, Birmingham; and in the latter part of the same year he entered into partnership with Mr. George Allcock. In 1850 the partnership was dissolved, and he commenced business on his own account. In that year he read a paper to this Institution on railway carriage and wagon springs (Proceedings 1850, Jan. page 19, and April page 14); and in October of the same year a paper on railway carrying stock, and papers on improvements in the construction of railway carrying stock (Proceedings 1851, Jan. page 10; and 1852, page 206). In 1851 he started the letting of railway wagons on the purchase-lease plan. In 1853 he took a leading part in forming the Midland Wagon Works, which were established at Rotherham, but eventually moved to Birmingham. In 1862 he joined as a director in the establishment of the Birmingham Joint Stock Bank. In the next year he and his partner, Mr. Henry Griffith, sold their business to the Midland Wagon Co., in which he retained his seat on the board of directors. About that time he became a director of Muntz's Metal Co. In

1873–4 he travelled extensively in America, and introduced in the United States the purchase-lease plan of letting railway wagons, for which purpose he formed the Union Rolling Stock Co. Throughout his life he was an ardent sportsman; he wrote a book entitled "Twenty-six years' reminiscences of Scotch grouse moors," and a pamphlet on "Bores and loads for sporting guns for British game shooting." He was a justice of the peace and deputy-lieutenant for the county of Hereford, and latterly took much interest in magisterial and other county work. Having had a slight paralytic stroke about four years previously, he had been an invalid for six months prior to his death, which took place from general natural decay at his residence at Gaines in Herefordshire, on 31st January 1896, at the age of seventy-four, a week before what would have been his golden wedding day. He became a Member of this Institution in 1848; and in 1865 an Associate of the Institution of Civil Engineers.

Daniel Kinnear Clark was born in Edinburgh on 17th July 1822, being the youngest of three sons of Mr. Daniel Clark, a merchant of that city. After serving his apprenticeship from 1839 to 1845 at the Phœnix Iron Works of Messrs. Thomas Edington and Sons, Glasgow, he became mechanical engineering draughtsman to Mr. John Miller of Edinburgh, who was chiefly connected with railway work. Here he utilized his spare time for two years as assistant editor of a local publication entitled the "Practical Mechanic and Engineer's Magazine." On leaving Mr. Miller's office in 1848 he entered the locomotive department of the North British Railway in Glasgow, but removed to London in 1851 to become engineer to the Deep Sea Fisheries Association, a post he retained until his return to Scotland in 1853. In 1852 he contributed two papers to this Institution on the expansive working of steam in locomotives (Proceedings 1852, pages 60, 109), which produced a discussion that added greatly to the knowledge of the locomotive. In 1853 he became locomotive superintendent of the Great North of Scotland Railway; but as the retention of this position involved a permanent residence in Aberdeen, he resigned it after a tenure of about eighteen months. His first published work of importance was

"Railway Machinery," which is even now regarded as a standard work on railway rolling stock. Originally published in parts and completed in 1855, this book at once established his reputation as an authority on locomotive engines. In the course of the six years occupied in its compilation he visited nearly all the railway works in England and Scotland. During his visits to London in connection with its publication, he was brought into contact with some of the leading engineers of that day, on whose advice he decided to commence practice in London as a consulting engineer. In 1855 he accordingly settled in the Adelphi, where he continued to practice for the rest of his life. The reputation which his "Railway Machinery" achieved in America led to his introduction to the late Zerah Colburn on the occasion of his coming to England shortly after its publication; and their meeting resulted in the publication in 1860 of a supplementary volume embracing the more recent practice in English and American locomotives. In 1853 he contributed to the Institution of Civil Engineers the first of a series of papers on the "Experimental Investigation of the principles of the Boilers of Locomotive Engines." Thirty years later these contributions were supplemented by a paper on the "Behaviour of Steam in the Cylinders of Locomotives during Expansion." In 1862 he was appointed superintendent of the machinery department of the International Exhibition held in London; and at its close received the thanks of the Commissioners of the Exhibition for the able manner in which his difficult and delicate duties had been carried out. A cyclopædia of the machinery, written by him, was published in 1864, entitled "The Exhibited Machinery of 1862;" and a paper on the "Locomotive Engines in the International Exhibition of 1862" was contributed to this Institution (Proceedings 1863, page 78). In 1869 and again in 1871 he proceeded to Egypt as Sir John Fowler's representative, to report on the railways of the country, and to prepare plans for a scheme of agricultural irrigation and for the construction of a ship railway at the first cataract of the Nile. Returning to London in 1872 he devoted himself mainly to literary work, the pursuit of which was well adapted to his studious tastes and retiring disposition. In 1877 was published his "Manual

of Rules, Tables, and Data for Mechanical Engineers," on which he had bestowed several years of labour in order to render it as perfect and complete as possible; it enjoys a high reputation as a leading work of reference, more especially among American engineers. In 1879 appeared his book on "Fuel; its Combustion and Economy," which may to some extent be regarded as the sequel to an invention brought out in 1857, having for its object the perfect combustion of fuel in furnaces by means of jets of steam introduced into the fire-box over the coal; this plan had already been applied successfully to a large number of stationary and locomotive boilers. In 1880 he was appointed testing engineer to the Smoke Abatement Committee, and in that capacity carried out a large number of tests of fuels and of heating and cooking apparatus in connection with the exhibitions held at South Kensington in 1881 and 1882, the results of which were embodied in a report published in 1883. His first work on "Tramways; their Construction and Working" was published in 1878, and was followed by supplementary and enlarged editions in 1882 and 1894. In 1892 was published his "Mechanical Engineer's Pocket Book," a comparatively little known but valuable work, containing a vast amount of original and useful information. By far the most important of his later works is "The Steam Engine: a treatise on Steam Engines and Boilers," published in 1892. It is probably by this exhaustive treatise that he will be best known to posterity; it may in fact be regarded as the master-piece of a long life devoted to the interests of the engineering profession. His last work, which was placed in the publisher's hands only a short time before his death, was an enlarged edition of his earlier work on "Tunnelling." The concluding years of his life were saddened by ill health resulting from over-work, which forbade all mental activity except at rare intervals. His death took place at his residence in Buckingham Street, Adelphi, London, on 22nd January 1896, at the age of seventy-three. He became a Member of this Institution in 1854, and was a Member of Council in 1863–4.

John Hayes was born in Liverpool in 1863. Having been educated at home and in private schools, and from 1873 to 1877

in the college of St. Francis Xavier, Liverpool, he served an apprenticeship of five years in the office of Messrs. W. P. Thompson and Co., consulting engineers, in Liverpool. He was engaged by them as draughtsman and assistant, and subsequently as assistant manager or managing clerk. For some time he was occupied in the preparation of working drawings for water meters at the Rainhill gas and water works. In 1894 he was taken into partnership, and became managing partner of the Birmingham office of the firm. While in a weak state of health he was accidentally run over and killed in Birmingham, on 7th September 1895, at the age of thirty-two. He became an Associate of this Institution in 1894.

Andrew Johnston was born at Stranraer, Wigtownshire, and received his education there. He served an apprenticeship of five years from 1861 with Messrs. W. and A. McOnie, Glasgow. In 1867 he went to China, and for eighteen months was superintending the erection of new machinery in Nankin Arsenal. From 1869 to 1875 he was employed as marine engineer on steamships trading on the coast of China. In 1875 he was appointed manager of the West Point Foundry, Hong Kong; and later on superintendent engineer of the Cosmopolitan Docks, Hong Kong. In 1881 he superintended the erection and fitting up of the Lee Yuen Sugar Refinery, Hong Kong, of which he continued manager till 1886. From that year he was established as a consulting engineer in Hong Kong, and acted also as Lloyd's surveyor at that port for machinery, and latterly for ships too. During 1889 he personally superintended the floating of the steamer "Ardgay," which had gone on shore when going full speed in the Gulf of Tonquin; and a severe typhoon coming on shortly afterwards, the vessel had been left practically high and dry on a sandy beach. The first attempt to get her off was all but successfully completed when a storm came on, and all the work had practically to be done over again; and it was only after arduous and long-continued efforts that the vessel was at last got off and towed to Hong Kong for repairs. Towards the end of 1895 he was in indifferent health, and in February 1896 left for a trip to America, in hopes of benefitting by the change; but he became worse during

the voyage, and on arriving at San Francisco was taken to the German hospital, where he died on 27th March 1896. He became a Member of this Institution in 1891.

THOMAS MEIK was born on 20th January 1812 at Duddingston, near Edinburgh. After being educated at the High School and University of Edinburgh, he worked for two years with a firm of millwrights named Moodie; and was then apprenticed to Mr. John Steedman, engineer and contractor, at that time engaged in building the Hutcheson Bridge at Glasgow. He next obtained an engagement upon the ordnance survey of Ireland; and in 1833 became assistant to Mr. W. C. Mylne, engineer to the New River Company, London, to which he ultimately became assistant engineer. In 1845 he was appointed engineer to the River Wear Commission, Sunderland; and from 1859, when the Commission took over the undertaking of the Sunderland Dock Co., he had charge of the whole works of the port until 1868, when he retired from the service of the Commissioners, while continuing to act as their consulting engineer. There he carried out extensive works, including the construction of the Hendon Dock with separate entrance from the sea, new breakwater, graving dock, grain warehouses, coal staiths, swing bridges, and extensive dredging operations. In 1868 he started business on his own account in Sunderland and Edinburgh, in partnership with Mr. W. D. Nisbet, with whom he carried out important works in the north of England and in Scotland, including docks at Burntisland and Ayr, harbour works at Warkworth and Blyth, waterworks at Bedlington, fore-shore protection at Bridlington Quay, the Hylton, Southwick, and Monkwearmouth Railway, and other smaller works. After dissolution of this partnership in 1875, he was joined by his two sons, with whom he carried out further works, including Boness Harbour and Dock, Eyemouth Harbour, and Eyemouth Branch Railway; and the firm also acted as consulting engineers to the new dock at Silloth for the North British Railway. He was consulted by many harbour authorities in the north of England and Scotland; and gave evidence before the Royal Commission upon Harbours of Refuge in 1859, and again before the

Fishery Harbour Commission in 1884. He was the first to introduce hydraulic coal-hoists into Scotland, the first of these being set to work at Burntisland in 1875; and he considered no dock works complete without machinery worked by hydraulic power. He retired from business in 1888, and had hardly known what illness was until a few months before his death, which took place at his residence in Edinburgh on 22nd April 1896, at the age of eighty-four. He became a Member of this Institution in 1858.

John Sinclair Pirrie was born in Belfast on 3rd May 1853. He served his apprenticeship from 1869 with Messrs. Harland and Wolff, Belfast, and with Messrs. James Jack, Rollo and Co., Liverpool. On its termination he was employed by Messrs. Laird Brothers, Birkenhead; and to gain experience went to sea for three years as a marine engineer. In 1876 he went to India to superintend the erection of compound surface-condensing engines and mill-gearing for Messrs. J. and E. Wood of Bolton, at the New Colaba Land and Mill Co.'s works in Bombay, and remained there for a year and a half as superintendent engineer. Subsequently for twelve months he was manager of the Byculla Engine Works, Bombay; and in 1878 became senior partner in the firm of Messrs. Fraser and Miller, Carnac Iron Works, Bombay. He returned to England in 1884, and entered into partnership in the firm of Timmins and Pirrie, London. In 1891 he was appointed a director of the Austral Otis Elevator and Engineering Works, South Melbourne, Australia. This position he held to the time of his death, which took place in Melbourne from heat apoplexy on 28th January 1896, in his forty-third year. He became a Member of this Institution in 1882.

Marshal M. Saïd, Pacha, was born at Eghin in Asiatic Turkey, in 1832. He was only eight months old when his father, S. Mustafa Aga, died while he was governor of Ismid in 1833. In 1847 he entered the Artillery and Civil Engineering College in Constantinople, and after completing his course of instruction there in 1853 he passed examinations, and was promoted to the rank of lieutenant, remaining

in the college as assistant teacher. He was considered by Professor Sang of Edinburgh, then professor of mathematics in the college, as one of his most intelligent scholars. After being promoted to the rank of lieutenant-major in 1854, he entered the University of Edinburgh, where he studied for five years, and passed well in his examinations, acquiring a thorough knowledge of English, and of natural science and mathematics. Returning to Constantinople in January 1859, he was promoted to the rank of major in August 1861, and became a member of the Imperial naval staff. In the same month he was sent to the Herakli coal mines for surveying. In 1863 he was sent to England by the ministry of artillery, as naval attaché to the Ottoman Embassy at the time when Musurus Pacha was ambassador, to inspect the artillery purchased for the Turkish government. Subsequently he was occupied with Mr. J. C. Frank Lee in improving the arsenal at Tophane, in which with the sanction of the war office they were assisted by the late Mr. (afterwards Sir) John Anderson of Woolwich Arsenal. Meanwhile he had been promoted in 1864 to be lieutenant-colonel and in 1865 to the rank of colonel. In 1867 he was appointed a member of the Council of Marine, and became in 1868 vice-admiral and director of the Naval College, which he raised to the rank of European colleges by the introduction of judicious improvements. Five years later he became a member of the commission for the construction of railways, under the Ministry of Public Works; and in 1875 was appointed director of the Technical Commission of the Ministry of Artillery. In 1876, on the accession of the present Sultan, he was promoted to the rank of admiral and appointed adjutant-general of the Imperial Palace; and in the same year he became lieutenant of the Minister of Marine, and then Minister of Marine and Director of the Military College. In 1877 he was promoted to the rank of Marshal of the Imperial Palace; and in 1878 was appointed Governor-General of the province of Angora in Asiatic Turkey. After acting in a similar capacity in other districts he retired in 1887. For his services he received the Order of the Medjidieh of the first class, and afterwards the Order of Imtiaz. He was the first native of Turkey to design a locomotive.

and to give lessons in mechanical engineering and the higher branches of mathematics in the Naval College. About a year before his death he had an attack of apoplexy, which deprived him of the use of his left side; another attack on 21st February 1896 proved fatal at the age of sixty-four. He became a Member of this Institution in 1864.

Robert Barlow Seddon was born on 9th February 1853 at Liverpool, being the second son of Mr. John Seddon of Wigan (Proceedings 1891, page 476). After serving his apprenticeship to the Metropolitan Railway Carriage and Wagon Co. from 1870 to 1874, he went to Wigan to become the secretary and manager of the Wigan Wagon Co. There he was actively associated with many of the institutions and public bodies in the district, being for many years a member of the Ince local board. He was also connected with the Douglas Forge, and interested in other local concerns. His death, resulting from a chill, took place at Hindley near Wigan on 20th October 1895 in the forty-third year of his age. He became a Member of this Institution in 1886.

Henry Tipping was born on 11th May 1839 at Patricroft near Manchester, and served his apprenticeship there as an engineer in the Bridgewater Foundry of Messrs. Nasmyth, Wilson and Co., for whom he subsequently superintended the erection of machinery at Woolwich Arsenal and other places. He was afterwards appointed surveyor to the Kirkham Coal and Iron Works, near Preston, where he served for four years. For about five years and a half he was engaged as manager to Messrs. Courtney, Stephens and Co., Blackhall Place Iron Works, Dublin; and for some six years as head draughtsman in H.M. Dockyard, Portsmouth. For the last fourteen years he was employed chiefly on his own account as consulting engineer, and designed several improvements in machinery, including a reversing gear to do away with the link motion in steam engines, a slide-valve, boiler, &c. One of the latest was an electric arc-lamp, for which he obtained a bronze medal at the Crystal Palace electrical exhibition in 1892. While returning from an exploring expedition in West Africa, he was

seized with malignant fever, contracted at Cape Coast Castle, and died near Sierra Leone on the voyage home on 12th May 1896 in the fifty-seventh year of his age. He became a Member of this Institution in 1886.

Francis William Willcox was born on 17th March 1840 in Birmingham, being the youngest son of Dr. Willcox of that town, and was educated at King Edward's Grammar School. In 1855 he was apprenticed to Messrs. Robert Napier and Sons, shipbuilders and engineers, Glasgow, with whom he remained seven years, during the latter part of which he had charge of the steam trials of the vessels engined by the firm, and often went to sea in charge of the machinery. While in Glasgow he attended Professor Rankine's lectures at the University. He then became assistant to Sir John Anderson, superintendent of machinery in Woolwich Arsenal; and had charge of machinery at home and at out stations, as well as of the steam vessels of the war department. In 1866 he went to Messrs. J. and G. Rennie, engineers and shipbuilders, London, as managing draughtsman and chief designer; and went for them to Egypt in connection with the fitting of compound engines in the Khedive's fleet. In 1870 he became manager and designer to Messrs. T. R. Oswald and Co., engineers and shipbuilders, Pallion, Sunderland. In 1872 he commenced practice in Sunderland in partnership with Mr. Wawn, as consulting and superintending engineers and naval architects; they carried out work for Lloyd's underwriters and for numerous insurance societies in various parts of the world, and also had the superintendence of a large fleet of steamers. He designed several mechanical devices, including a steam and hydraulic steering gear, ventilators for ships' holds, and a screw propeller; these were fitted to upwards of six hundred vessels in numerous ports at home and abroad. His death occurred at his residence in Sunderland after four days' illness on 30th April 1896 at the age of fifty-six. He became a Member of this Institution in 1885; and was also a Member of the Institution of Engineers and Shipbuilders in Scotland, and of the North-East Coast Institution of Engineers and Shipbuilders.

Institution of Mechanical Engineers.

PROCEEDINGS.

April 1896.

The Spring Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Wednesday, 29th April 1896, at Half-past Seven o'clock p.m.; E. Windsor Richards, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following fifty-two candidates were found to be duly elected:—

MEMBERS.

Baker, William Henry,	Gwalior.
Cook, Charles,	London.
Cottrell, Stephen Butler,	Liverpool.
Dronsfield, William,	Oldham.
Dryden, Thomas,	Preston.
Ekin, Tom Charles,	London.
Ferguson, William Deeble,	Belfast.
Holman, Frederick,	Penzance.
Lane, Francis Lawrence,	Leeds.
Leisse, George Charles,	Leeds.
McPherson, Stewart,	Calcutta.

Morley, Herbert William,	Bradford.
Price, James,	Cork.
Scriven, Charles,	Leeds.
Thomas, James Martin,	Liverpool.
Toone, William Carson,	Warminster.
Trotter, Alexander Pelham,	Cape Town.
Watson, James Falshaw,	Leeds.
Wheeler, Percy,	Oldbury.
Williamson, Joseph,	São Paulo.

ASSOCIATE MEMBERS.

Barker, Arthur Henry,	London.
Bosley, Walter Joseph,	Stoke-by-Guildford.
Cooper, Thomas,	London.
Cox, Edward Henry,	New York.
Davidson, John McKenzie,	Karachi.
Gallé, William Alexandre,	Manchester.
Gray, Alexander Cuthill,	Glasgow.
Heath, Charles Lewis Eclair,	Sheffield.
Hill, Thomas,	Glasgow.
Hollingsworth, Edward Massey,	St. Helen's, Lancs.
Johnson, Thomas Oliver,	Glasgow.
Jones, Thomas Gilbert,	Huddersfield.
Lawson, Harry John,	London.
Malloch, William Farquhar,	Johannesburg.
McCormack, William John,	London.
New, David James,	London.
Patel, Motibhai Bhikhabhai,	Bolton.
Patel, Raojibhai Motibhai,	Bolton.
Pritchard, Hugh,	Llanberis.
Rayner, Harry Stafford,	London.
Scanlan, Horace Edward,	Poole.
Stobart, Henry Gervas,	Wolsingham.
Vallint, Frank William,	Calcutta.

ASSOCIATE.

Harvey, Julius,	London.

GRADUATES.

Crow, Lewis,	Paisley.
Dawe, John Nanscawen,	Glasgow.
Gordon, Leslie,	Thames Ditton.
Hodgson, George Henry,	Newcastle, N.S.W.
Johnson, Henry Howard,	Erith.
Kitsell, Archibald Edward,	London.
Pinel, Paul Gustave Marie,	Rouen.
Simpson, Norman De Lisle,	Derby.

The President announced that Members of the Institution were invited to take part in a Mining and Geological Congress to be held in September in Budapest, in connection with the Hungarian Millennial National Exhibition.

The President further announced that since the last meeting the purchase had now been completed of the site at Storey's Gate for the Institution House. Tenders for building the house had been received, of which the lowest had been accepted; and a contract would shortly be signed for its erection.

The President then delivered his Inaugural Address: after which the Discussion was resumed upon Mr. William H. Patchell's paper, "Notes on Steam Superheating," which had been read and partly discussed at the previous Meeting.

At Ten o'clock the Discussion was adjourned to Friday evening, 1st May. The attendance was 81 Members and 58 Visitors.

The Adjourned Meeting was held at the Institution of Civil Engineers, London, on Friday, 1st May 1896, at Half-past Seven o'clock p.m.; E. Windsor Richards, Esq., President, in the chair.

The Discussion upon Mr. Patchell's "Notes on Steam Superheating" was continued and concluded; and the following Paper was read and discussed:—

"Steel Steam-Pipes and Fittings, and Benardos Arc Welding in connection therewith;" by Mr. Samuel MacCarthy, of London.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in allowing the use of their rooms for the Meeting of this Institution.

The Meeting then terminated at a Quarter to Ten o'clock. The attendance was 58 Members and 91 Visitors.

The Anniversary Dinner of the Institution was held at The Freemasons' Tavern, Great Queen Street, Lincoln's Inn Fields, on Thursday evening, 30th April 1896, and was largely attended by the Members and their friends. The President occupied the chair: and the Guest of the evening was His Excellency the Honourable Thomas F. Bayard, Ambassador of the United States of America. The following Guests also accepted the invitations sent to them, though those marked with an asterisk* were unavoidably prevented at the last from being present. Sir Frederick A. Abel, Bart., K.C.B., D.C.L., F.R.S., Honorary Life Member; Sir Renny Watson; Professor W. Cawthorne Unwin, F.R.S., Honorary Life Member.

Mr. Joseph Nasmith, President of the Manchester Association of Engineers; Sir William Arrol, LL.D., M.P., President of the Institution of Engineers and Shipbuilders in Scotland; Dr. John Hopkinson,* F.R.S., President of the Institution of Electrical Engineers; Mr. W. Lloyd Wise, President of the Chartered Institute

of Patent Agents; Mr. Thomas Richardson, M.P., President of the North-East Coast Institution of Engineers and Shipbuilders; Mr. Archibald Denny,* President of the Institution of Junior Engineers; Sir Edwyn S. Dawes, K.C.M.G., President of the Institute of Marine Engineers.

Professor W. C. Roberts-Austen, C.B., F.R.S., Chemist to the Royal Mint; Professor D. E. Hughes, F.R.S.; Professor T. Hudson Beare, F.R.S.E.; Mr. Frederic W. Burstall; Lt.-Colonel Thomas English; Mr. William Gowland*; Mr. Samuel MacCarthy; Mr. Hugh McPhail; Mr. William H. Patchell; Mr. Charles J. Wilson, F.I.C.; Mr. Frank Wright.*

Mr. William G. R. Bousfield; Mr. William Dunk; Mr. Harry Lee Millar,* Treasurer; Mr. Basil Slade.

The President was supported by the following Officers of the Institution:—*Past-Presidents,* Dr. William Anderson,* C.B., F.R.S.; Sir Edward H. Carbutt, Bart.; Mr. Jeremiah Head; and Professor Alexander B. W. Kennedy,* LL.D., F.R.S. *Vice-President,* Mr. Edward P. Martin. *Members of Council,* Mr. John A. F. Aspinall, Mr. Henry Davey,* Mr. William Dean, Mr. Bryan Donkin, Dr. John Hopkinson,* F.R.S., Mr. Arthur Keen,* Mr. Thomas Mudd,* Mr. James Platt, and Mr. A. Tannett Walker.

After the usual loyal toasts, Sir E. Leader Williams proposed that of "The Navy and the Army," which was acknowledged by Lt.-Colonel Thomas English. The toast of "Our Guests," proposed by the President, was acknowledged by His Excellency the Honourable Thomas F. Bayard, Ambassador of the United States of America. Sir Frederick A. Abel, Bart., K.C.B., D.C.L., F.R.S., proposed the toast of "The Houses of Parliament," which was acknowledged by Sir William Arrol, LL.D., M.P. The toast of "Kindred Societies," proposed by Mr. A. Tannett Walker, Member of Council, was acknowledged by Mr. Thomas Richardson, M.P., President of the North-East Coast Institution of Engineers and Shipbuilders. The concluding toast of "The Institution of Mechanical Engineers" was proposed by Professor W. C. Roberts-Austen, C.B., F.R.S., and acknowledged by the President.

ADDRESS BY THE PRESIDENT,

E. WINDSOR RICHARDS, Esq.

In glancing over the many able addresses of former Presidents of this and cognate Institutions, I observe that the opening remarks often refer to the difficulty experienced in finding subjects to discourse upon. I too must commence in the same manner; for I confess I have found it a most difficult task to decide upon themes, which could be either interesting or instructive to so learned a body of engineers and metallurgists as that forming the Institution of Mechanical Engineers. Our Institution does not confine its attention solely to the construction of machinery, as our papers and discussions show. We are equally interested, scientifically, practically, and commercially, not only in the designing of every description of installation, but also in the Manufacture itself of Iron and Steel: so that probably I need not use words of apology for departing somewhat from the path generally followed by Presidents when addressing the Institution.

Much has been persistently said and written for some time past about the decadence of our metallurgical and engineering industries; it has been alleged that the machinery we employ is neither so economical nor so efficient as that of late years adopted in competing countries; that our commerce has declined for want of energy and enterprise on our part; and that we are being rapidly outstripped in the race for the supremacy which we have so long enjoyed. As all the Members are deeply concerned in this matter, and are pre-eminently those who should remove these reproaches if they are found to be merited, I thought I would lay before you some examples of actual practice, for enabling us to judge to what extent the charges

made against us can be justified. This subject having been decided upon, it was my intention at the outset to describe the principal features of the machinery and plant in use at home and abroad for the manufacture of iron and steel, from pig-iron to the finished products of rails, plates, billets, girders, and wire-rods. But it soon became evident that with the limited time at my disposal it would be impossible to do justice even to the first portion, namely the manufacture of pig-iron: so that on this occasion I must confine my observations almost exclusively to blast-furnace engineering. The principal object then of this address is to direct the attention of metallurgical engineers to Blast-Furnace Practice as it stands today, with regard to production, efficiency of appliances, and economy of results obtained; and, where possible, to give cost of labour per ton of material produced; and so to ascertain the relative positions and prospects in this department of engineering metallurgy, at Home, and in America, Germany, Luxemburg, France, and Belgium.

You are aware that in the summer of last year a delegation organised through the British Iron Trade Association visited Belgium and Germany, with the view of ascertaining how it was that those countries were able not only to compete with us in neutral markets, but also to send their products into our own country. The report of the delegation has been printed and published, and gives a large amount of interesting information, showing that the subjects enquired into have received most careful thought and attention. The enquiry must have entailed great labour, much time and consideration, and considerable tact. The members of the delegation are certainly entitled to the best thanks of all interested in engineering and metallurgical industries. The report deals more fully with the details of the cost of the labour of making finished iron and steel than with that of making pig-iron; and directs attention to the much lower rates of wages ruling in those countries, more especially in Belgium, than here. The conclusions arrived at are, that much more care and attention are given abroad than at home to details of working, that the workmen are far more industrious, and less given to strikes than ours; but the main question we have to consider after all is, what is the total labour-cost per ton of

material produced, rather than upon how low a rate of wages a continental workman can live, in comparison with the rates ruling here. I am always inclined to believe that, even with the higher rates paid to labour, the cost per ton is not so much more than that with the so-called cheap labour. This view would seem to be confirmed by the statement made by Mr. Herbert, Secretary to the American Navy. He says that the United States can build better warships at a cheaper rate than any other country except Great Britain, which is in that respect but slightly in the front; and he adds that American ships are however, type for type, equal to the best in the British Navy. Now as labour forms so large a percentage of the cost of building a ship, it would seem that a highly paid workman is more efficient than a cheaply paid one.

Many conflicting statements are made as to the extent to which continental countries can compete with us now, or are likely to compete with us in the near future; and this subject is of such vital importance to us as to call for an exceptional amount of attention at our hands, for we are naturally most desirous not to relinquish any of our trade in neutral markets, and especially are we anxious that material from abroad should not be sent into this country. It is necessary to bear in mind, when accusing ourselves of want of enterprise, that we should make an important and broadly marked distinction between competition which is founded on merits—that is, on the capacity of one country to produce a commodity cheaper than another by virtue of the possession of cheaper or more effective labour, cheaper materials, cheaper transport, or more modern equipment and plant—and competition which is protected by tariffs. In the examples I am about to cite, the information has been gathered by visits to the several countries, and inspection of the various works; but as such descriptions in an address of an hour's duration can only be briefly dealt with, and principal figures only can be given, it would be greatly to the advantage of the Institution if the members would take up the subjects touched upon, and contribute papers giving fuller descriptions, and so by raising discussion bring out results of working which would greatly benefit the industry.

British Productions and Blast-Furnaces.—In the years 1881–82–83, which were years of fairly good trade, the production of all descriptions of pig-iron, spiegel-eisen, and ferro-manganese in Great Britain averaged in round figures 8,500,000 tons per annum. In 1893, a year of bad trade everywhere, the production had fallen to 6,829,841 tons. In 1894 the production had increased to 7,364,841 tons, obtained from 323 blast-furnaces, giving an average of 22,800 tons per furnace. As these results cannot be considered satisfactory when compared with those of other countries, the following figures show in which districts the outputs were lowest. They are given in the order of production; and allowance must be made for those making cold-blast iron, and using coal, and rich or comparatively poor ores.

District.	Tons.	Furnaces.	Average per furnace.
Cleveland	2,963,419	87	34,062
South Wales	708,856	22	32,220
West Cumberland	674,840	20	33,742
Scotland	655,614	50	13,112
Lancashire	593,023	20	29,651
South Staffordshire and Worcestershire	315,924	25	12,637
Lincolnshire	287,384	13	22,106
Nottinghamshire and Leicestershire	226,950	14	16,210
Northamptonshire	212,411	14	15,172
Derbyshire	210,860	20	10,543
South and West Yorkshire	202,255	13	15,558
North Staffordshire	195,809	13	15,062

The total production of pig-iron in 1895 was about 7,900,000 tons.

To the Cleveland district more than to any other must be given the credit of having greatly improved blast-furnace construction and practice; and it still maintains the leading position in this country in the production of all descriptions of iron and steel. For many years it was a school which engineers of all countries visited to their benefit. The district is much indebted to such men as Vaughan, Bell, Gjers, and many others. It was here that Cowper's fire-brick stove was brought to a practical success by Cochrane, who put up the pioneer stove to heat the blast for one tuyere only. This

stove was filled with regenerative bricks, and heated from below by coal burnt on a grate, allowing the cold gases to escape through a chimney fixed on the top of the stove; it was not long before the bottom bricks proved unequal to the support of the bricks above, and the result was a collapse, but not before decided success had been attained in economy of fuel, due to the increased temperature of blast obtained. Encouraged by this success, a pair of stoves was erected sufficient to heat the blast for one furnace, and was set to work in October 1860. Subsequently to these applications of fire-brick stoves, Whitwell's apparatus for heating the blast was adopted at Consett, and rapidly extended to other districts, as well as to France, Belgium and Germany, and the United States. The adoption of this system of heating the blast effected a saving of about $2\frac{1}{2}$ cwts. of coke per ton of pig-iron, above that obtained by cast-iron pipe-stoves, besides permitting a higher pressure of blast to be used, and thus increasing the output of the furnace; indeed the invention of fire-brick stoves rendered possible the large productions of today.

Last year's work of Messrs. Cochrane's three furnaces, which have been fully described in the Proceedings of the Institution, shows highly interesting figures. With ironstone from the Cleveland mines they made 123,594 tons of pig-iron over the whole of 1895, being an average of 41,198 tons per furnace, or at the rate of 792 tons per furnace per week, with an expenditure of 21·12 cwts. of coke per ton of iron. The average temperature of the blast over the twelve months was 1,490° Fahr.

A good and fair example of the working of a Cleveland blast-furnace over the last twenty years, using native ironstone containing raw an average of 29 per cent. of iron and calcined 41 per cent., is furnished by No. 8 furnace at Eston, shown in Plate 17, which was put into blast in 1874 and blown out in 1894, having made from one lining 484,412 tons of pig-iron. During that period the furnace was damped down thirteen weeks, in consequence of the Durham colliers' strike. The average output per annum was 24,000 tons. Formerly cast-iron pipes were used for heating the blast, but latterly Cowper stoves. During the last year of its working it made 26,168·14 tons

of good grey iron, using 26,891·18 tons of coke, being an average of 500 tons of iron per week and 20·55 cwts. of coke per ton of pig.

Furnaces erected at Eston in 1877 continue to produce a little under 1,000 tons of Bessemer iron per week, using 50 per cent. ores. The best of these furnaces produced last year 50,800 tons of iron with 18·60 cwts. of Durham coke per ton of pig. These furnaces without any arrangements for cooling the boshes last about five years, and give about 250,000 tons of iron, and then require re-lining. With present engine-power the above quantity cannot be increased; it has therefore been decided to erect six vertical direct-acting high-pressure engines, as there is no water available for condensing; the air cylinders are 84 inches diameter and 5 feet stroke. These engines of exceptional strength are being constructed by Messrs. Tannett Walker and Co., Leeds, and are to supply 25,000 cubic feet of air per minute at from 8 to 10 lbs. pressure per square inch to each of three blast-furnaces. The boilers are of the Lancashire type, 30 feet long, and 8 feet diameter, with two flues 3 ft. 3 ins. diameter, having five cross Galloway tubes, and are to work at 80 lbs. pressure: so that greatly improved results in working are expected to follow shortly upon their completion.

At Jarrow-on-Tyne a blast-furnace plant was constructed with all recent improvements, from which greatly improved results were expected. As these results were not at first realised, it is of value to ascertain the causes, in order to avoid similar failure in future. The furnace No. 5, shown in Plate 18, is 75 feet high, bosh 20 feet diameter, having several cooling plates, angle of bosh 80°, hearth 11 feet diameter, throat 16 feet, bell 11 feet, capacity of furnace 14,150 cubic feet, eight gun-metal tuyeres $5\frac{1}{2}$ inches diameter, placed 6 feet above the hearth level. Blast of $3\frac{1}{4}$ lbs. pressure per square inch, heated by four Cowper stoves, 73 feet high and 22 feet diameter, to a temperature of from 1,400° to 1,500° Fahr. Durham coke with 8 per cent. ash and 1 per cent. sulphur, $19\frac{1}{2}$ cwts. per ton of Bessemer pig-iron. Production 1,000 tons per week from Bilbao and African ores averaging 50 per cent. of iron, increased to 1,100 tons during the last few weeks. Limestone 8 cwts. per ton of

pig. One pair of compound condensing vertical blast-engines, high-pressure cylinder 54 inches diameter, low-pressure cylinder 72 inches diameter, air cylinders 100 inches diameter, stroke 5 feet, making 17 revolutions per minute for 1,000 tons of iron per week. From such an installation as this it would be expected that a large production would be readily obtained at a low cost; but the furnace worked with great irregularity, and was continually hanging and slipping. Increased blast-pressures were tried, and failed to produce any improved results. The cause was evidently traceable to the steep boshes. So unsatisfactory and costly was the working that the furnace was blown out in June 1893, and the boshes were altered to 68°, as shown in Fig. 3, Plate 19. Since this alteration the furnace has worked well and economically. The engineering portion of the whole plant is well carried out. For a furnace having such a large reserve of blast and heating power, an output of only 1,100 tons per week cannot be considered a good return for the large amount of money expended.

In a paper read and discussed at the Middlesbrough meeting of this Institution in August 1893, our Past-President, Mr. Jeremiah Head, described a blast-furnace of peculiar internal form, Fig. 5, Plate 20, designed by Messrs. Hawdon and Howson of Middlesbrough. On visiting last month the works of Sir Bernhard Samuelson and Co. in order to ascertain what success this new form of furnace had attained, I found there are five now in operation, giving such satisfactory results that a sixth is being prepared. Two of the furnaces were making Cleveland iron, and three hematite. No. 5 furnace with 18 feet bosh, 65° angle, 11 feet hearth, 84 feet high, had made during the previous ten weeks, with Rubio ore containing 50 per cent. of iron, an average of 1,053 tons per week of good grey Bessemer iron with a consumption of 18·1 cwts. of coke per ton of iron, the coke containing 10 per cent. of ash. The blast is supplied by ordinary vertical compound condensing quick-running engines at about 4½ lbs. pressure per square inch, and is heated by Cowper stoves to 1,400° or 1,500° Fahr. By increasing the volume and maintaining the heat of the blast, Mr. Hawdon expects shortly to attain 1,200 tons per week.

The Dowlais Cardiff new blast-furnace plant is remarkable for efficient and economical working. The two furnaces, shown in Fig. 4, Plate 19, have 20 feet boshes, 10 feet hearths, and are 75 feet high; and from Bilbao ores containing 50 per cent. of iron each furnace produces 1,250 tons per week of good grey Bessemer iron with a little over 19 cwts. of coke per ton. The production can be readily increased.

From the foregoing statements and descriptions, which can be compared later with the figures obtained in other countries, it will be seen that present British practice with ores containing 50 per cent. of iron averages 1,000 tons of pig per week, with a strong tendency to increase. The coke consumption varies from 18½ to 20 cwts. per ton of pig. Labour cost, including everything in connection with the blast-furnaces, from unloading the ores to loading up the pig-iron, but excluding establishment charges, is as low in one instance as 24*d.* per ton of pig, rising to 30*d.* for hematite iron, and to 36*d.* for Cleveland iron.

Having described a sufficient number of works to give a fairly adequate idea of the state of blast-furnace practice at home, I now pass on to the consideration of the American pig-iron industry.

American Blast-Furnaces.—Taking the same periods as before, namely the three years 1881–82–83, we find the average production of all descriptions of pig-iron for each of these years was 4,500,000 tons; and it has since increased by leaps and bounds, till in 1895 the enormous production was reached of 9,446,308 gross tons; the previous year being one of bad trade, the output was 6,657,388 gross tons. In the month of March of the present year 1896 there were 203 furnaces in operation, giving an average output of 48,000 tons per furnace per annum: so that it is probable the total production of the present year will reach ten million tons. The average production is not of much value, as in the above number there are twenty charcoal furnaces in operation. American blast-furnace practice is by far the most interesting and instructive of all; it is receiving the most careful study of continental engineers, and merits our best consideration.

At South Chicago and at many other works there are furnaces doing really marvellous work. A type of furnace which has worked most satisfactorily and economically at the Edgar Thomson Works, Plate 21, is 91 feet high, 20 feet bosh, having an angle of 75°, throat 16 feet diameter, crucible 13 feet diameter, eight tuyeres placed 8 ft. 6 ins. above the level of the hearth, projecting 6 inches inside the lining, and having nozzles 8 inches diameter; Cowper fire-brick stoves heating the blast to about 1,200° Fahr. Each furnace is blown by two single vertical blast-engines, having steam cylinders 40 inches diameter, and air cylinders 84 inches diameter, together supplying about 26,000 cubic feet of air per minute at 10 lbs. pressure. This furnace produces the extraordinary quantity of 11,000 tons of Bessemer pig-iron per month, when using Lake ores containing 62 per cent. of iron. On many days of 24 hours the output exceeds 400 tons, using the very small quantity of 1,790 lbs. of Connellsville coke to 2,240 lbs. of iron, the coke containing 11 to 12 per cent. of ash.

The desirability and economy of these large productions of iron are questioned by many engineers and managers, owing to the hitherto great wear and tear and speedy destruction of the brickwork forming the lining of the furnace. But these objections have latterly been to a great extent surmounted, and are now best answered by the results obtained from furnace I at the Edgar Thomson Works. This furnace has been in blast for more than five years, and has made over 650,000 tons of iron, with an average coke consumption, including all stoppages through strikes and other causes, of 1,889 lbs. per 2,240 lbs. of iron.

Special means of preserving the bosh lines of the furnaces are adopted, and are highly effective; indeed the success attained is due in a great measure to this plan, which greatly prolongs the life of the furnace. Cooling plates or flat water-boxes are placed in rows about 2 feet apart, from the top of the tuyeres up to the height of the top of the boshes; they are made of gun-metal, about 5 feet long, shaped to the curves of the furnace, and placed about 6 inches away from the inside line of the bosh; they are about 4 inches wide by

3 inches thick, and have water running continuously through. The two rows above the tuyeres, and the second and third above these, are connected together to save water; and above them three rows of plates are connected together. Before being put into position the cooling plates are tested by hydraulic pressure. Should a plate leak at any time during working, it can be readily withdrawn and another substituted. The crucible below the tuyeres is kept cool by a strong cast-iron plate surrounding the furnace; a coil of $1\frac{1}{4}$-inch pipe is cast therein, which serves for the circulation of water.

Another bold change has been made in the size of the bricks used in the construction of the furnace. Formerly, and as is the practice now in other countries, a huge lump of clay was used, sometimes as large as 30 inches long, 15 inches wide, and 6 inches thick. Such a mass it was almost impossible to bake thoroughly to the core. Of late years we have reduced this thickness to 3 inches with improved results; but the sizes now used in America have been reduced to $13\frac{1}{2}$ inches long by 3 inches thick, and 9 inches by 3 inches to break joints, the whole 3 feet thickness of the furnace walls being made up of two $13\frac{1}{2}$-inch and one 9-inch brick.

In order to obtain a large output with economical results, American practice adopts a large hearth and a comparatively small diameter of bosh; the latter gives as much iron as the larger bosh, and uses less fuel per ton of iron by reason of the gases being distributed equally and rapidly over all the ore, and not working in channels as with a larger bosh. The quantity of iron produced depends on the power of the furnace to burn fuel, and in order to do this a large hearth is necessary, together with a large volume of high-pressure blast; when these are provided, the narrower the bosh the more oxygen is removed from the ores by the gases and less by solid carbon; hence lower fuel consumption.

My own practice goes to prove that a furnace rapidly driven works with greater regularity and gives a more even quality of iron, lower in silicon, than a furnace slowly driven. However much some may disagree with fast driving, every furnace manager in Europe whom I have seen for the purpose of this inquiry, whilst professing

to be satisfied with the output he had already attained, was at the same time making some addition or alteration, whereby he expected to obtain increased production and diminished cost.

Mr. Carnegie is so satisfied with the great economy of the results he has already obtained that he is constructing four more furnaces, Plate 22, and in a few weeks will have two of them in operation at his Duquesne Works near Pittsburg. The results of the working of these furnaces will be eagerly watched by all European and American engineers. The following are the leading particulars of this installation, which is to cost about £600,000. Height of furnace 100 feet, bosh 22 feet diameter, angle of bosh 74°, crucible $14\frac{1}{2}$ feet diameter, throat 17 feet, bell $12\frac{1}{2}$ feet, ten tuyeres 8 inches diameter, placed 9 ft. 8 ins. above the level of the hearth. There are to be five pairs of blast engines, of vertical compound condensing beam types, Plates 25 to 29, having high-pressure cylinder 40 inches diameter and low-pressure cylinder 78 inches diameter, two air-cylinders 76 inches diameter and 5 feet stroke; the ordinary speed is to be 40 revolutions per minute, at which speed each pair of engines will deliver 25,000 cubic feet of air per minute at from 16 to 18 lbs. pressure per square inch; the maximum speed will be 50 revolutions, and maximum pressure of air 25 lbs. A production of 500 tons in 24 hours is expected from each furnace, being at the rate of 180,000 tons per annum; and if the lining endures only four years of such work, the satisfactory quantity of 700,000 tons will be obtained, a quantity which an English furnace would require fourteen years to produce. There are twenty-four Babcock and Wilcox 250-H.P. boilers, with two steam drums for each boiler, 36 inches diameter and $23\frac{1}{4}$ feet long, and 126 tubes 4 inches diameter and 18 feet long; the tubes are arranged in fourteen sections per boiler, nine tubes in each section. Each furnace has four Cowper-Kennedy stoves with central combustion chamber, height 96 feet, diameter 21 feet. Every appliance for saving labour, and every improvement which their great experience has shown, will be adopted. Whilst generally in America the whole labour-cost per ton of Bessemer pig-iron is from 80 cents to one dollar, it is reported that this new plant will reduce the cost nearly one-half.

One more example of the working of an American smaller plant. Furnace 77 feet high, bosh 19 feet diameter, crucible 11 feet, six tuyeres 6 inches diameter, four Massicks and Crookes stoves. Production last year 81,780 tons, or 220 tons per day, of Bessemer pig-iron from Lake ores. Ore 3,940 lbs. per ton of iron, coke 2,060 lbs., limestone 780 lbs. Total labour-cost 1·05 dollar.

Germany and Luxemburg come next in production. The average of the three years 1881–82–83 was 3,254,844 metric tons of all descriptions of pig-iron; and the output increased each year, till in 1894 it amounted to 5,345,632 tons and in 1895 to 5,431,007 tons, being an average of about 28,000 tons per coke furnace per annum in the Dortmund and Bonn districts. Stimulated by the adoption of a protective tariff and by the invention of the dephosphorization process of steel making, Germany rapidly developed all her industries, and enjoys great and increasing prosperity. Luxemburg contributes a large quantity of pig-iron to German steel works, besides supplying important quantities of Minette ironstone.

At Esch in the Grand Duchy of Luxemburg there are four blast-furnaces in operation, making together about 800 tons of basic pig-iron per day, which is sent by railway 120 to 150 miles to Westphalia at the low carriage-rate of 10 francs per ton. This blast-furnace plant of the Société de Luxembourgeois is considered the most important in that region. For the last month the furnaces made their largest average of 202 tons per day, using Westphalian coke containing about 8 per cent. of ash, and Minette ironstone, the best in that district, with Greek manganiferous ore to reduce sulphur, and additions of basic slag to give phosphorus up to 2·2 per cent. A new furnace is being constructed, and will be put into operation this autumn; the height is 82 feet, bosh 23 feet diameter, angle 73°, hearth $11\frac{1}{2}$ feet, throat 15 feet. There is much dust in the furnaces, and it is supposed to lie on the boshes, forming a protection to the brickwork, and so water cooling-plates are said to be of no practical advantage. In order as much as possible to prevent the dust from passing into the stoves, there are six tubes 8 ft. 2 ins. diameter and 66 feet high, resting in a pan

of water; the dust passing alternately down and up these tubes has time to deposit itself in the water, and is scraped out without stopping the blast. Five Cowper stoves, 83 feet high and 23 feet diameter, heat the blast to 900° C. or 1,650° Fahr.; there are seven tuyeres of 7 inches diameter. For these high stoves a powerful draught is absolutely necessary. The chimney is 270 feet high and 11½ feet diameter at the outlet. A horizontal compound condensing engine, making 24 strokes per minute, supplies 22,000 cubic feet of air at 7 lbs. pressure per square inch, with steam at 6½ atmospheres; high-pressure cylinder 52 inches diameter, low-pressure 78 inches, air cylinders 100 inches diameter, stroke 5 feet 3 inches. They have never succeeded in getting these cylinders to work without cooling them with water. For the new furnace a vertical compound condensing engine is being constructed at Bayenthal.

At Uckange in Lorraine, on the Moselle, there is a smaller and well arranged new plant of three furnaces, two in operation, each making about 123 tons per day. The furnaces use Minette ironstone containing from 33 to 34 per cent. of iron, obtained from their mines about two miles distant. A new furnace in course of construction and nearly completed is 65 feet high, bosh 19½ feet diameter, hearth 9 feet 9 inches. Four tuyeres of 7 inches diameter. Four Cowper stoves 62 feet high, 21¼ feet diameter. Directly after leaving the furnace the gas is conveyed to a receiver of large diameter, the bottom part of which is tapered to receive a valve easily opened for discharging the dust thus collected. The gas is further passed through ascending and descending wrought-iron tubes of considerable height and diameter, and by lowering its speed gives time for more dust to become deposited on the surface of the water receptacle below; the mud thus obtained can then be easily scraped out. By these means a large proportion of the dust is prevented from entering the stoves and boilers. There are three vertical compound blast-engines.

At Ruhrort I found the largest German production; the output at two furnaces for the thirty-one days of last month (March) was 16,800 tons from ores averaging 40 per cent. of iron. The furnace was said to be 88 feet high, but the useful height would probably be

nearer 80 feet. Bosh $21\frac{1}{2}$ feet diameter, angle 63°, protected by several water-blocks; hearth $12\frac{1}{2}$ feet diameter. Eight tuyeres of 7 inches diameter; nozzle pipes red-hot by daylight; pressure of blast $\frac{3}{4}$ atmosphere. Four Cowper stoves 98 feet high and 26 feet diameter. The furnace was lined with carbon bricks up to the boshes only; the bricks are thus kept well below the region of carbonic-acid gas, and so far are doing well. A Bayenthal compound condensing vertical blast-engine running at 45 revolutions per minute drove one blast-furnace. It was said that this engine could run well at 60 revolutions per minute; but with the complicated cut-off gear such a speed would soon necessitate considerable repairs. The air cylinders were 78 inches diameter with 6 feet stroke.

Another set of eight blast-furnaces in that district—seven in blast producing together 25,000 tons per month of basic, foundry-pig, and ferro-manganese containing up to 80 per cent. of manganese—whilst working fairly well, offered nothing specially favourable to record, except that, being fully alive to keep to the front, they have just erected and nearly completed the first of eight pairs of horizontal compound condensing blast-engines, having air cylinders 80 inches diameter and 5 feet stroke; and whilst the manager expressed himself satisfied that 150 tons per day of basic iron is ample for a furnace, he is providing sufficient blast-power to give 200 tons. The Minette ironstone from Luxemburg costs 3*s.* 6*d.* per ton, and carriage 6*s.* 6*d.* This is mixed with Swedish Grängesberg ore, containing 60 per cent. of iron and 1 per cent. of phosphorus, costing 15*s.* 6*d.* f.o.b. at Ruhrort; and with puddlers' tap-cinder from England. The basic pig-iron so produced, containing 0·5 per cent. of silicon and 2 per cent. of phosphorus, is conveyed to a 120-ton mixer, where the sulphur is reduced to a very low percentage by the addition of manganese. The whole of the 18,000 tons of steel produced monthly at these works is made by the dephosphorization process; indeed very little acid steel is now made in Germany, the former being preferred.

At Mr. Friedrich Krupp's works at Essen both acid and basic steels are made; but Mr. Asthöwer informed me the best steel made in their large crucible shed is manufactured from puddled iron—a

somewhat despised material today—which is selected and cut up in suitable pieces for the crucibles. In this large casting-house they make four casts of crucible steel every day of 24 hours. Crucible castings up to 80 tons are made from twenty-three Siemens above-ground furnaces, which hold 100 crucibles containing 50 kilos each. All the castings of varying weights that I examined looked perfectly solid and free from blow-holes. All rails, plates, and girders are made by the dephosphorizing process, either Bessemer or Siemens. The shop containing the forging presses, plate-rolling mill, &c., is a magnificent structure. The plate mill has forged steel rolls, 4 feet diameter and 13 feet long, driven by a pair of horizontal reversing engines geared $2\frac{1}{2}$ to 1, the rolls making about 32 revolutions per minute. I saw a deck-plate rolled from an ingot 20 inches thick, and reduced to 2 inches in twelve minutes. Some plates for boilers lying on the floor, 12 tons weight, measured $45\frac{1}{2}$ feet long, $11\frac{1}{2}$ feet wide, and $1\frac{1}{4}$ inch thick, made to form the complete circle of a boiler. An ingot mould to receive an 80-ton charge measured $11\frac{1}{2}$ feet by 36 inches by 13 feet deep. Mr. Krupp owns twelve blast-furnaces, and will commence building at Rheinhausen eight of modern type, each to make 180 tons per day; three are to be at work this year. The blowing engines are to be of the same pattern as those at work at Micheville in France, described later on.

My friend, Mr. Consul Hoesch, is building some blast-furnaces at his steel works near Dortmund, Plate 24. My powers of description will give only an inadequate idea of the magnificence of this installation. The works are laid out for four furnaces, two of which, commenced last July, are erected, and will be in operation this summer. The coal for coke-making is washed and crushed, and stocked in capacious bunkers, placed sufficiently high for it to flow into small wagons with bottom doors for charging through apertures in the tops of the ovens. The Coppée coke ovens, with some improvements by Dr. Otto, are arranged at one end of the works in two groups of fifty each. The by-products, consisting of sulphate of ammonia, oils, and pitch, are obtained; and the cleaned gases are utilised for heating the walls of the ovens and raising steam. Each oven produces 4 tons

of dense coke per 24 hours, at a cost of about 10*s.* per ton. The coke is conveyed by overhead railway to the blast-furnaces. The ores are stocked in exceptionally large and numerous bunkers, each 230 feet long and 33 feet deep, entailing a heavy first outlay, because the Swedish ore can be obtained from the Lulea region during five months only of the year, owing to the mines being frozen up during the rest of the year. This ore is estimated to cost about 17*s.* per ton at the works. The two furnaces, Plate 23, are 75 feet high, 22 feet bosh rising $18\frac{3}{4}$ feet, angle 75°, crucible 11 feet diameter, 8 ft. 2 ins. high, throat 14 ft. 8 ins., central tube for taking off the gases with two downcomers, six tuyeres of 5 inches diameter. Ten Cowper stoves, 92 feet high, $21\frac{1}{4}$ feet diameter, with chimney 245 feet high, outside diameter at bottom $16\frac{1}{4}$ feet and at top $10\frac{3}{4}$ feet. Twenty-four Lancashire boilers 7 ft. 2 ins. diameter, 34 feet long, two tubes each 30 inches diameter without cross tubes, heating surface 95 square metres or 1,020 square feet. The two furnaces, placed 114 feet apart from centre to centre, have separate hoists and roofed cast-houses; and the hearth level is high enough above the general level for the slag and molten iron to flow into cast-iron boxes and ladles, to be conveyed to the heap or to the steel works. For the two furnaces there are four compound condensing horizontal blast-engines, with high-pressure cylinder 42 inches diameter, low-pressure 60 inches, air cylinders 75 inches, and stroke $5\frac{1}{2}$ feet, to make from 35 to 40 revolutions per minute. Steam pressure $8\frac{1}{2}$ atmospheres, and blast pressure from one-half to one atmosphere, as may be required. The 100 coke ovens with by-product plant are estimated to cost £75,000; the two blast-furnaces, with all railways, bunkers, &c., £150,000.

At a works where the production of pig-iron was very large, the cost of labour was as low as 1*s.* 9*d.* per ton. The total cost, including general and establishment charges, was only 3*s.* 3*d.* per ton.

In 1882 the production of Bessemer iron was 733,665 tons, and it has fallen now to 350,000 tons; whilst in 1883 the production of Thomas iron—that is, pig-iron run into cast-iron moulds for the Bessemer basic process, made specially low in silicon so as to contain

only about 0·5 per cent.—was 369,685 tons, and it has constantly and regularly increased, till it has now reached the enormous total of $2\frac{1}{2}$ million tons. Germany is entitled to the highest credit for her skill, industry, and perseverance in this rapid and great development of the basic dephosphorization process of steel making. This unexampled success has enabled her to use her own phosphoric minerals to an important extent, and to produce a material used for every purpose, where the highest quality is an absolute necessity.

France follows with an average output in the three years 1881–82–83 of 2,000,000 metric tons, which declined in 1886 to 1,516,574 tons, and gradually increased to 2,005,889 tons in 1895, when there were seventy furnaces in blast, giving an average of about 30,000 tons per furnace per annum.

The furnaces in the Centre, South, and North of France making Bessemer pig-iron have made little, if any, progress for some years; but great impetus was given to the production of phosphoric pig-iron in the East of France by the invention of the dephosphorization process of steel making. In the Meurthe and Moselle district there are forty-three blast-furnaces, which produced last year 1,264,000 tons, being an average of 30,000 tons per furnace per annum, leaving only 813,647 tons for the whole of the remaining furnaces of the country.

Engineers in the whole of the Lorraine and Luxemburg districts have paid great attention to blast-furnace construction and production; they state that they consider the essential points to be borne in mind for regularity of working and large production are, that every furnace should have numerous Cowper stoves, and should have its own blast-power isolated from that of other furnaces. Their most economical and best results have been attained, firstly by increased size of furnace; secondly, by higher temperature of blast; thirdly, by more powerful blast-engines.

The ironstone used is the well known Minette, of three qualities —red, grey, and calcareous. These either by themselves, or mixed with one another, require neither additions of limestone in the furnace nor calcination. The ironstone in the neighbourhood of

Longwy averages a little over 30 per cent. of iron. The coke is brought from Westphalia, a distance of more than 150 miles, and costs delivered 21·30 francs per ton; the price into wagons in Westphalia is 10 francs, and the duty 1·30 francs per ton. Labour cost per ton of iron varies from 25*d.* to 30*d.* The class of iron made throughout this district is mostly Thomas iron; and in order to make it high enough in phosphorus, namely to contain about 2 per cent., an addition of phosphoric slag from the converter is necessary, as the Minette by itself gives only 1·5 per cent. of phosphorus. Greek ore is also added to give about 1·8 per cent. of manganese in the iron, so as to keep the sulphur down to about 0·6 or 0·8 per cent., the iron being white. Generally from 1,150 to 1,200 kilogrammes of Westphalian coke is required for making 1,000 kilos of iron. The forge and foundry iron is almost identical in character and analysis with Cleveland iron.

At Micheville two furnaces have recently been put in blast, which are excellent types of good construction. By the courtesy of Mr. Ferry, I am able to give the following description. Height of furnaces 80 feet; bosh 22 feet diameter, angle 72°; hearth 10 feet; throat 16¼ feet diameter. This large diameter of throat enables capacious charging apparatus to be used, and the charges are exceptionally heavy, consisting of coke 5½ tons and ironstone 15 tons, or 1,200 kilos of coke to 1,000 of pig-iron. There is no greater economy found in heavy over light charges, except that the apparatus is opened less often, and there is consequently less loss of gas. A disc valve of about 16 feet diameter is lowered on the ridge of the apparatus, to prevent the escape of gas when the materials are being lowered into the furnace; but as it is difficult to make so large a valve quite gas-tight, there is some escape, though not very considerable. There are only four tuyeres at work, though provision is made for seven. The average production is nearly 150 tons per day. There are four Cowper stoves to each furnace, 80 feet high and 23 feet diameter. Two pairs of vertical compound condensing blast-engines, made by the Société Alsacienne of Mulhouse, are of excellent design, strongly made, and of good workmanship: high-pressure cylinders 36 inches diameter, low-pressure 50 inches, air-

cylinders 78 inches diameter, stroke 5 feet, and 32 revolutions per minute. The governor is adjustable to give the number of revolutions fixed upon by the manager, the pressure of the blast being disregarded. As there is not far away from the blast-furnaces a steel works producing 10,000 tons of steel per month, which will soon be increased to 12,000 tons, the engineer, Mr. Hartmann, has paid the closest attention to the economical use of the furnace gases, with the view of working the engines in the whole of the works without using coal under the boilers. There are in all at Micheville four blast-furnaces, producing about 3,500 tons per week; one is open-topped, that is, there is a central tube taking off sufficient gas to work the blowing engine and Cowper stoves in connection with the furnace, and the remainder of the gas is allowed to escape. When the whole of this gas is utilised by cup and cone arrangement, and six more boilers now nearly ready for work are completed, there will be seen at Villerupt a steel works having a pair of vertical compound Bessemer blowing-engines for the basic converters, a compound condensing cogging-mill engine, a compound condensing rolling-mill engine with three-high billet and bloom and slab rolls, all of which, with all the small engines, will be supplied with steam from the blast-furnace gases, after these have heated the hot-blast stoves and worked the furnace blowing-engines. The boilers have large combustion chambers, below the level of the floor, and are of the multitubular kind, having 208 square metres or 2,240 square feet of heating surface; and the tubes are so arranged that they can be brushed out whilst the boiler is at work. A thin layer of blast-furnace dust deposited in the tubes largely curtails the power of the boilers to produce steam; six hours without cleaning shows a marked difference in the quantity of steam raised; two men are therefore constantly employed in brushing out the tubes of twelve boilers. The gases escape from the boilers at a temperature of 280° C. or 540° Fahr., and after passing through Green's economisers are reduced to 160° or 180° C., or 320° or 360° Fahr. The steam pressure is 8 atmospheres.

The ingots are taken as hot as possible from the Bessemer department, placed in Gjers soaking pits, in which a small quantity

of coal is used, and then rolled off. An English order for basic billets $2\frac{1}{4}$ inches square had just been completed, and delivered in Antwerp at 103 francs per ton, a distance of 150 miles, at a cost for carriage, wagon-hire &c., of 7 francs per ton. The labour cost per ton of pig is 2·80 francs, and the total cost 40 francs per ton. The cost varies in different districts; the Westphalian syndicate having different prices for coke for different districts, all calculations of costs are rendered most complicated and difficult.

The molten metal is conveyed direct from the blast-furnaces to a mixer of 120 tons capacity, and from there to three basic converters some distance away.

At the Aciéries de Longwy Mont St. Martin there is an important plant of half-a-dozen blast-furnaces, with steel works having three 15-ton basic converters and extensive rolling mills. Whilst the materials produced are of a high character, there is nothing of special importance to call for attention.

Belgium.—The average production per annum for the years 1881–82–83 was 711,705 metric tons, which declined in 1891 to 684,126 tons, and afterwards increased, till in 1895 the production was 816,039 tons from thirty furnaces in blast, the average output per furnace being about 27,000 tons. The production is still increasing. Although poor in iron ores, Belgium is advancing in blast-furnace practice, and intends to hold a leading position.

The Société John Cockerill has constructed in the best possible manner, and just put into operation, a very fine blast-furnace installation, having all the most recent improvements. By the courtesy of Mr. Greiner, Director-General of the Company, I had the pleasure of being present at the starting of the furnace on the 30th of last month (March), when the Minister of Public Works travelled from Brussels to light the fire, and wished success to the furnace, and increased commercial prosperity to this most successful company, and to the material interests of the Kingdom of Belgium—an instance of the great interest taken by the Government in the development of the industries of the country. The furnace, Fig. 6, Plate 20, is 78 feet high, bosh 20 feet diameter, angle $71\frac{1}{2}°$. There are five

tiers of water blocks above the tuyeres to protect the lining of the boshes. Hearth 10 feet diameter at the bottom, widening to 11 feet at the level of the tuyeres. Seven tuyeres of 5 inches diameter, placed 9 feet apart from nose to nose, and $6\frac{1}{4}$ feet high above the level of the hearth. Throat 15 feet diameter, having two gas outlets to one large downcomer, which leads into a capacious receptacle containing water for cleaning the gases. Four Cowper stoves, lined with octagonal bricks, are 82 feet high and 22 feet diameter; the chimney with wrought-iron casing lined with bricks is 230 feet high, with a clear outlet of 10 feet diameter.

One of the blast-engines is a copy of a type adopted at some American works. It has two outside fly-wheels, an arrangement which makes it difficult to reach readily some of the working parts. It is a single vertical quick-running engine, with air cylinder 84 inches diameter placed above the steam cylinder, which is 42 inches diameter. The maximum steam-pressure is six atmospheres, and the valve-gear has somewhat complicated motions for early cut-off. The stroke is 5 feet, and the speed 40 revolutions per minute, with the intention of running up to 60; if found desirable the pressure of blast may be increased to one atmosphere. A second engine is being constructed of better design, and of greater power and more strongly made, consisting of a pair of vertical compound condensing engines, with a single large fly-wheel in the centre of the shaft; high-pressure cylinder 30 inches, low-pressure 48 inches, two air-cylinders each 68 inches diameter, stroke 4 feet, to make from 40 to 60 revolutions per minute; and pressure of air from 7 lbs. to 10 lbs. per square inch.

Great attention has been given to the boilers; they are 9 feet 10 inches diameter, and have each three tubes; the two top tubes are 3 feet 3 inches diameter, and the bottom one 2 feet 8 inches; length $32\frac{1}{2}$ feet. The boilers are fired by the gas from the furnace; and each tube has a separate chamber of large capacity, to insure complete combustion.

Westphalian coke is used. The ores are principally Tafna, Rubio, and purple, all low in phosphorus, for making Bessemer pig-iron. From the ordinary furnaces about 100 tons are obtained

daily; and from the new furnace much better results are expected, probably 200 tons a day.

At the works of La Providence, Marchienne, Mr. Hovine has two furnaces in operation, and a new one is being constructed. Those at work each produce 110 tons daily of basic pig; and the new one, which is larger, is expected to give 140 tons daily. There are altogether seven furnaces in operation making phosphoric pig-iron, the steel works using nothing but basic pig. These works are celebrated for the low prices at which they export girders &c. to England. A rolling mill having three-cylinder engines was rolling girders in a three-high train at a high speed, direct from ingots heated in coal-fired furnaces.

The labour cost per ton of Bessemer iron is $2\frac{1}{2}$ francs; 4 francs cover all kinds of labour and salaries; and another franc is found a sufficient fund for relining. Labour at basic furnaces is 3 francs per ton of iron, little, if any, limestone being used.

Belgium having last year reduced its tariff has commenced to complain of Germany throwing some of its surplus production into the country at very low prices.

Several other blast-furnaces are being constructed abroad; but sufficient has been said to show that they recognise the vital importance of obtaining suitable and cheap pig-iron. Great efforts are being made, and large sums of money expended, to produce it in greater quantities and at lower costs.

From the foregoing figures of production and descriptions of plant, it can be seen that great progress is being made abroad, whilst our production of pig-iron compared with the average of the three years 1881–82–83 remains stationary. America has doubled her output. Germany and Luxemburg are increasing so rapidly that probably this year will see their output also doubled, and they are steadily and rapidly advancing to our figures. France remains stationary. Belgium has increased 13 per cent.

Fuel.—With respect to our position as regards fuel, the cost of coal varies considerably in the several regions; but the following

figures of values, supplied to the Secretary of the Board of Trade by Sir Robert Giffen, indicate pretty accurately the relative costs or production in the five countries, and show that as regards Germany our costs are alike, but are considerably lower than those of France and Belgium. In 1894 the United Kingdom and the other countries here mentioned produced the following quantities of coal of the average values named per ton at the pit:—

United Kingdom	produced	188,277,000	tons at	6s. 8d.	per ton.
United States	,,	158,000,000	,,	5s. 3¼d.	,,
Germany	,,	76,741,000	,,	6s. 7½d.	,,
France	,,	26,964,000	,,	9s. 0¼d.	,,
Belgium	,,	20,534,000	,,	7s. 5½d.	,,

Iron Ores.—Swedish phosphoric and Spanish hematite are somewhat dearer on the Continent than with us; but the Minette ironstone costs only about 2*s*. per ton at the mines, whilst similar ironstone at home costs more, being burdened with a royalty charge of about 6*d*. per ton.

Railway Rates.—We have seen that low railway rates abroad permit of carrying low qualities of ironstone to furnaces 150 miles distant from the mines, and also of carrying coke from Westphalia to the Luxemburg, French, and Belgian blast-furnaces to make pig-iron, and afterwards of carrying the pig-iron made in Luxemburg and Lorraine to Westphalia to be converted into finished products. In this country it must be admitted that we have a splendid railway service, and that the dividends paid are only fair and reasonable; but the rates of carriage are out of all proportion heavier than those ruling abroad.

Labour Cost.—As regards the labour cost per ton of iron, there is not much difference to our disadvantage: so that it is misleading to accuse ourselves of inability to compete from this cause. But there is no doubt whatever that our labour has become far more difficult to manage, is much more ready to stop work in order to obtain an increase of wages, and is constantly agitating for fewer hours of work. Every concession made renders it more and more difficult to

compete with the Continent in the markets of the world; but our workmen cannot yet be brought to see this, neither can they be persuaded to cease opposition to mechanical devices for saving labour and reducing costs; indeed all such appliances are jealously watched, and if possible their success is prevented. Yet the favourite remedy for this state of things in many minds is to spread technical education all over the country; whereas, if the result they desire could unhappily be attained, the last state of the trade would be worse than the first, for we should have no hewers of coal nor makers of steel. The truth is that there is no lack of technical ability in this country: quite the contrary. Our continental competitors do not claim to have invented the puddling process, the rolling mill, the steam hammer, the Bessemer acid and basic processes, the hot-blast stove, &c.; but they have carefully applied all these processes and inventions of ours to their own use, in a scientific and practical manner; and we are equally free to adopt their methods, if any of them are better than our own. But they can and do claim that they have trained skilful, careful, and obedient workmen. Whilst I do not concede that a continental workman understands his duties better than our workmen, I do most distinctly believe that his military training has been of great advantage to him, to his physique, and to his employers. A compulsory strict military training, to follow the sound and excellent education now given to every one, would contribute greatly to the general good of our country. Our path is strewn with difficulties; but the greatest difficulty we have to surmount, which seems insurmountable, is the barrier of tariffs set up against us. For, whilst Great Britain is free and open to attack from all the world, America demands a payment of 16*s.* 8*d.* for every ton of pig-iron we send there, Germany 10*s.* per ton, France 15 francs minimum; and Belgium, brave little kingdom, surrounded by powerful competitors, reduced its duty in July of last year from 5 to 2 francs. In these tariffs lies the real reason of the success of foreign competition; but we have no right to complain, for these barriers have enabled those countries to develop their resources and to employ their own population. But we do complain, when, after having supplied their own requirements at prices that leave them

good profits, they throw their surplus products into our country and into our colonies at lowered prices. Remove these barriers, and then the reproachful cries we are fond of raising against ourselves—of want of technical knowledge and ability, want of energy and enterprise, and decadence of our industries—would become cries of the past; and the race for supremacy would be a race run on merits.

Mr. William Laird, Member of Council, in moving a vote of thanks to the President for his Address, said he was glad the President had been able to preface the address by announcing that the preliminary arrangements had now been made and a contract was about to be entered into for a suitable building for the Institution. They had for many years been beholden to the Institution of Civil Engineers for the use of the lecture room in which they were now assembled; and any rumours of what the Institution of Mechanical Engineers might be about to do in providing a meeting room for themselves had not lessened the friendly interest felt by the Council of the Institution of Civil Engineers, who had continued to hold out the brotherly hand of fellowship, and had permitted them again to occupy these new rooms. It was highly gratifying that the younger Institution should again be so kindly welcomed by the older.

All knew how wide was the experience of their President in the subject which he had dealt with in the Address just delivered; and the care which he must have taken in preparing this address was an indication of how greatly he valued the high position he occupied at the head of this Institution. Not only had he been in communication with the leading makers of pig-iron in this country, on the continent, and in America, but he had taken the trouble to collect from them and from other sources figures which could be fully relied upon, and to bring forward the diagrams by which the address was so well illustrated. As far as he could do so in the time, he wished to enable all the members to be masters of the subject upon which he

had dwelt. It was a most appropriate subject for him to have taken up with his ability and experience, because it showed what might be called the cradle of the iron-making industry, and under what circumstances iron was produced from different kinds of ore in different kinds of furnaces and under different labour conditions. Had time allowed indeed, he might perhaps have taken up some special subjects connected with the iron-manufacturing industries, such as the finished products indicated at the outset of the address—" rails, plates, billets, girders, and wire-rods"—perhaps including also the making of tubes, large and small, especially the small tubes of particularly high quality which had been made during the last few years. At the present time an extensive industry was growing up in America in making such tubes for bicycles and tricycles. How long the demand for them would continue, no one knew. Some thought the cycle was going to displace horsemanship; and it would certainly compete closely with the new kinds of carriages driven by motors, with regard to which a bill was now before parliament. But these subjects the President had rightly said should be taken up and dealt with one by one. He had himself shown an example of most industrious investigation in the first stage, namely as to how iron was made; and he left it to other members of the Institution who might be specially conversant with particular branches to extend their observations, and to place before future meetings their experience and their views on these different topics. The present address had given all engineers much food for reflection, and had supplied most interesting statistics as to what was being done in England and elsewhere. Like an Englishman the President had spoken with great fairness, and was certainly encouraging in his statements, while at the same time he had pointed out that it would not do to be too self-satisfied, and that we had not got the field entirely to ourselves. This was a remark which did not apply to iron-making alone; it applied to every industry that he knew of; certainly it applied forcibly to the shipbuilding industry, in which he was himself specially engaged, as well as to many others in connection with iron and steel work, and also to the manufacture of textile fabrics. The President he thought had acted wisely in calling

(Mr. William Laird.)

special attention to what had been done in other countries. There it was true that English ideas might have been taken up and valuable inventions appropriated; but this had not been done blindly, but had been backed up by science, practical knowledge, and patience, with the further advantage of highly trained, industrious, and well-behaved workmen. Though English workmen might perhaps be the highest skilled of any in the world, yet others were following them closely; and it was their duty to take care that in their respective departments they were not surpassed. In thanking the President cordially for his excellent Address, he joined in the hope that it might have the intended effect (page 108) among the members of the Institution at large.

Mr. Jeremiah Head, Past-President, said all present had listened to a most interesting Address, and all must feel that they required to read it over again at least once before they could properly make their own all the information it contained. One conclusion however at which all must have arrived was that there was great benefit in looking over the high hedge which surrounded us, and seeing what others were doing on the other side. The President was a great traveller; he went into foreign countries, and saw what was being done there; he saw it with intelligent and observant eyes, and what he saw he made a note of. In his own opinion English manufacturers did not travel nearly enough. From the United States engineers were continually coming over to Europe to see what ideas they could pick up. Mr. Carnegie he believed made a practice of sending a couple of his managers to Europe every year for three months on a holiday, paying their salaries and their expenses, only requiring of them that they should go to other works in the same line of business as theirs, make themselves as agreeable as possible, and pick up all the knowledge they could. Such a course was perfectly within his rights; and it would be wise, he thought, if English engineers did a little more of the same kind of thing. On all sides foreigners were encroaching on our trade, and in many respects were getting in front of us. As the President had pointed out, this was partly due to the stimulus provided by their protective

tariffs. These of course we could not help; but there were many ways in which foreigners were getting ahead of Englishmen, which we could help, and in these it was not creditable to us that we should fall astern. In America, for example—where iron, brass, and other metals were dearer than in this country, where labour was also dearer, where the distances to the sea coast were greater, where they had not such a fleet of steamers to foreign countries as we had—they nevertheless exported machinery to a considerable extent every year to this country and to other parts of the world. Many of our old industries, such as watch-making, the Americans had to a great extent taken from us, notwithstanding the fact that their materials and labour were dearer. This was because they had gone into the manufacture more systematically and more scientifically. Englishmen might have done the same, and might do the same now, but they had not done it yet. Other productions also might be mentioned, such as sewing machines, which the Americans exported largely every year. Surely we ought to be as ingenious as they. At all events we had had an equal chance of inventing the sewing machine, and improving it, and exporting it all over the world. But it was not usual to discuss presidential addresses; and he must therefore revert to his immediate object, which was to second the proposal of Mr. Laird, that a hearty vote of thanks be given to the President for his most interesting and instructive Address.

The vote of thanks was passed with applause.

The President thanked the members cordially for the kind vote they had passed. He had been afraid they would find the Address long and tedious; but he had found he could not bring any other subject into an hour's discourse if he wished to do anything like justice to blast-furnace work. To the latter indeed he thought he had not done sufficient justice, even as it was. Still, if the members of the Institution would, as he had asked them, take the subject up, go carefully into it, and bring forward papers of their own, he should feel that the Address had been of some use to the Institution.

NOTES ON STEAM SUPERHEATING.

By Mr. WILLIAM H. PATCHELL, of London.

Nature of Steam Superheating.—Superheated Steam is steam of any pressure at a temperature higher than the temperature of its evaporation from water at that pressure. Saturated steam may be superheated by imparting additional heat to it at a constant pressure, during which process its volume increases. By permitting saturated steam of a given pressure to expand without doing work, superheated steam at a lower pressure may be formed. Steam cannot be superheated in the presence of the water from which it was evaporated, owing to the fact that the water takes up the heat and evaporates into further saturated steam. The corollary follows that water cannot exist in the presence of superheated steam: either the surplus heat n the steam will evaporate the water; or, if there be too little surplus heat to evaporate all the water, the steam will immediately become saturated by evaporating as much of the water as it can.

Messrs. Fairbairn and Tate, Hirn, and Siemens, all found that saturated steam was not a true gas, and that its expansion on the application of further heat was at first much greater than that of a perfect gas. When a temperature of about 20° Fahr. above that of the saturated steam was reached, the volume increased at about the same rate as that of a perfect gas. No data appear to be yet available as to the expansion of steam with high degrees of superheat; but there is little doubt that it would be that of a perfect gas. A marked feature in the use of superheated steam is the rapid fall in the superheat from radiation &c. The reason of this more rapid fall in temperature as compared with saturated steam seems to be that the latter owes its heat-retaining properties to the water spray

carried in it. It is only after this water spray has been evaporated that the steam becomes a true gas.

Aim of Superheating.—The greatest advantage to be gained by the use of superheated steam is in engine cylinders, and is due to the immediate absorption of the film of water on the metal surfaces by the surplus heat, thereby counteracting cylinder condensation, which is the heaviest loss in the expansive working of steam. In this connection superheated steam would appear to have an advantage over steam-jackets, inasmuch as the heat is applied exactly where it is wanted, and during the period that it is wanted, that is, up to the point of cut-off; whereas a steam-jacket wastes a considerable part of its heat and time in warming up the exhaust.

Early attempts at Superheating.—That economy attends the use of superheated steam in engine cylinders has been known at least since 1828, when Richard Trevithick reported on the engines at Binner Downs Mine in Cornwall.* The engineer of the mine, Capt. Gregor, wishing to rival the record of a neighbouring mine where the cylinders had been cleaded in saw-dust, built in his cylinders and steam-pipes with brickwork, making a fire-grate underneath them and flues around. The results were unexpected, and the duty of the engine was raised from forty-one to sixty-three million foot-pounds per bushel (84 lbs.) of coal. Trevithick tested the 70-inch cylinder engine, which, when 5 bushels of coal was burned in 24 hours under the cylinder, took 67 bushels under the boiler; when no coal was burned under the cylinder, 108 bushels of coal was used under the boiler for the same work, showing a saving of one-third of the coal by superheating. The steam pressure was 45 lbs. per square inch, and the strokes eight per minute. With the cylinder fires on, 13 gallons of injection condensing water was used per stroke, and heated from 70° to 104°; without the cylinder fires, 15½ gallons of condensing water was used per stroke, and heated from 70° to 112°. Trevithick followed this up by inventing in 1832 a tubular boiler, combined with a superheater between the boiler and the engine

* Life of Richard Trevithick, vol. 2, pages 315 and 323–4.

cylinder; he also jacketed the cylinder with the waste gases from the furnace. In Plate 30 is shown the arrangement, copied from his specification No. 6308 of 1832. The external series of vertical pipes, connected top and bottom to a hollow ring, constitute the boiler; the superheating pipes inside it are formed like inverted siphons, so as to avoid jointing at the lower end next the fire. Trevithick had been combating cylinder condensation for thirty years before this date, having in 1802 in conjunction with Vivian constructed a non-condensing engine, the cylinder of which was placed inside the boiler—a plan followed for many years with much success in agricultural portable engines by Messrs. Hornsby of Grantham.

Owing doubtless to the difficulty in controlling the temperature imparted to the steam, superheating made but little headway till 1850, when it came to the front again. Many plans were then proposed for superheaters and steam driers in various forms, both attached to boiler flues and separately fired. Asbestos packings and brass bushes with plumbago plugs were then introduced to meet the demand for steam-tight glands under superheated steam.

More recent efforts.—Some results then obtained were reported to this Institution by Mr. John Penn in 1859 (Proceedings page 195), followed by Mr. John N. Ryder in 1860 (page 22). Mr. Penn described the apparatus employed by him in the Valetta steamer of the Peninsular and Oriental Co., with engines of 260 nominal horse-power, where the saving in fuel due to superheating was 20 per cent. The superheater consisted of two horizontal faggots, each of forty-four 2-inch tubes, placed in the smoke-box. The tubes were fixed into three wrought-iron boxes, welded up at the corners and closed with a flanged joint. The steam from the boiler passed into the centre box, thence through the tubes into the end boxes on its way to the engines, taking up heat from the escaping gases which would have been otherwise wasted. The proportions of the apparatus are given by Mr. Penn as $2\frac{3}{4}$ square feet of superheating surface per nominal horse-power; the boilers had a heating surface of 19 square feet per nominal horse-power. The steam pressure was 20 lbs. per square inch, and the amount of superheat about 100° Fahr.

Mr. John N. Ryder dealt with Messrs. Parson and Pilgrim's apparatus as fitted on marine boilers, and also Mr. David Patridge's superheater. The Parson and Pilgrim apparatus consisted of two horse-shoe pipes fixed over the fire-grate in the internal flue of the boiler. Tests on the steamers Osprey and Swift showed a saving over saturated steam of 30 to 40 per cent. in fuel; and on H.M. steam-tug Bustler a mean of thirty-seven trials with a pressure of $8\frac{1}{2}$ lbs. and a temperature of 380° in the cylinders, which is 144° of superheat, gave 25 per cent. economy.

Mr. Patridge's apparatus was a cylinder filled with tubes, placed vertically in the uptake. The gases passed through the tubes, and the steam around them; the working temperature was from 360° to 390°. H.M. steamship Dee was fitted and tested for several months by the Admiralty, when an economy of fuel of from 20 to 25 per cent. was obtained. An aggregate of about 5,000 horse-power was stated to be then working with this apparatus.

Following closely on Mr. Ryder's paper was one read by the Hon. John Wethered, of the United States, at the Institution of Civil Engineers (Proceedings 1860, vol. xix, page 462), wherein he animadverted on the futility of the common kinds of superheater, and strongly advised mixed or combined steam, which he claimed to have introduced from America four years previously.

Reasons for former abandonment.—If superheating was so common and of such manifest importance and efficiency in the saving of fuel some forty years ago, the question arises, why was it given up? and what factors that led to its abandonment have been eliminated in modern practice?

Trouble was formerly experienced at the valve faces and in the cylinders from the decomposition and destruction, at the high temperatures of superheated steam, of the tallow and the low-class lubricants then in vogue. This trouble was twofold: the cutting and excessive wear in the absence of lubrication; and the pitting caused by the fatty acids in the lubricant. On this score however no trouble need now be anticipated, at any degree of superheat likely to be attained, where good hydro-carbon oils are used. Gas engines

run in regular working with a cylinder temperature in the neighbourhood of 2,000° Fahr., lubricated with good oil; and with ordinary care and attention instances of cutting are not frequent. The common use of metallic packings for glands, and of piston valves in place of flat valves, has removed another serious obstacle. In this connection it will be well to note that pistons and valves which show little leakage when used with saturated steam may show considerable leakage with dry steam, probably owing to the film of water on the metal improving the fit when saturated steam is used.

Much of the trouble that has been attributed to the effects of superheat, in respect of cut cylinders and valve faces, has in the author's opinion been due in reality to the effect of alternate superheat and water in the steam, owing to want of proper control of the superheaters. A superheater may give a high degree of superheat when the fires are in good order, and at another time may even act as a condenser. The effect of this alternation demands much closer attention than it has at present received. A somewhat parallel case is the behaviour of a good hydro-carbon cylinder-oil, which in one engine with normal dry steam leaves no deposit; whereas in a sister engine, at the same steam-pressure, with wet steam a heavy deposit is formed from the same oil.

An instance of a cut cylinder which had to be re-bored has lately come under the author's notice, where it appears from the evidence that the trouble is not to be attributed either to the degree of superheat in itself, or to the lubricant, or to neglect on the part of the engineer in charge, but to the alternate effects of superheated and wet steam in the cylinder.

The majority of the old troubles were met with in the engines; but the superheaters themselves do not appear to have been always above reproach. When endeavouring to trace failures to faults in pipes or joints, the author has sometimes found superheaters which were fixed with a by-pass for the steam, but none for the gases. The boilers were then worked occasionally with the steam shut off from the superheater; and it is not surprising that the latter deteriorated rapidly, its position being eminently unsuitable for a combination of boxes, pipes, and tube-joints.

Re-introduction of Superheating Apparatus.—Concurrently with the increased efficiencies gained in late years in both boilers and engines, competition has also increased; and with it has arisen the continual cry for cheaper power, cheaper transport, cheaper means of production. The result is that engineers cannot afford to dismiss without careful examination the claims of any plan, the adoption of which may diminish the consumption of fuel. It is this fact which has again brought superheating to the front, and has made it the subject of close enquiry in many quarters. Several kinds of superheater are now in more or less extensive use; but only one of them is a radical departure from those of forty years ago. Any change in the others is rather in manufacture than in design; and their parentage can be traced by their strong family likeness.

Gehre's Superheater.—This is in extensive use on the Continent, and has been introduced into this country by Messrs. B. Donkin and Co. of Bermondsey. It is shown in Plates 31 and 32, and may be either fitted in the boiler flue, Plate 31, or separately fired, Plate 32. Some of these superheaters have been fixed in England, but unfortunately they have not been tested. Mr. Bryan Donkin kindly gave the author a copy of a test made in Germany, of eight hours' duration, on a water-tube boiler without and with the superheater, Table 1. The heating

TABLE 1.—*Boiler Test* Without *and* With *Gehre's Superheater.*
See Plate 32.

Without or With Superheater		Without	With
Total Coal used during trial	lbs.	1,940	1,550
„ Water „ „ „	lbs.	15,100	15,400
Temperature of Feed-water	Fahr.	201°	205°
Superheat in Steam	Fahr.	—	40°
Temperature of Furnace Gases before superheater	Fahr.	600°	600°
„ „ „ after „	Fahr.	—.	510°
Water evaporated per lb. of coal	lbs.	7·82	9·99
Water evap. per sq. ft. of heating surface per hour	lbs.	2·20	2·23
Pressure of steam per sq. inch above atm.	lbs.	110–114	110–114
More Steam used	per cent.	5	—
Less Coal used	per cent.	—	34
Less Work on engine	per cent.	7	—

surface of the boiler was 861 square feet, and of the superheater 646 square feet. The superheater was placed directly behind the boiler in a special flue.

Musgrave and Dixon's Superheater.—By the courtesy of Messrs. Hick, Hargreaves and Co., the author has been favoured with the following particulars and tests, Table 2, of this superheating apparatus fitted at one of Messrs. Musgrave's cotton mills at Bolton. As shown in Plate 33, the apparatus consists of a nest of U tubes, bent to a large radius at the bottom, Fig. 9, which are placed at the back of a Lancashire boiler where the hottest gases from the flues impinge upon them. The tubes are suspended from a tube-plate, forming the bottom of a box, Fig. 10, in which they are fixed by being expanded in the usual manner. The box is divided down the middle by a vertical diaphragm, so that the saturated steam entering at one side passes down and up through the tubes, and leaves superheated at the other side. A by-pass valve is arranged to regulate the flow of steam through the superheater, because only a portion of the steam from the boiler is intended to be superheated. Main valves are also provided, so that the superheater can be disconnected for examination, or even taken out entirely, without interrupting the working of the boiler. The Lancashire boiler to which the superheater is applied is $8\frac{1}{2}$ feet diameter and 30 feet long, with two flues of $3\frac{1}{4}$ feet diameter, having nine circulating tubes in each. The grate surface is 39 square feet; the heating surface in the boiler is 1,195 square feet, and in the superheater 120 square feet. The area of passage through the superheating pipes is 22 square inches. The boiler pressure is 100 lbs. per square inch above atmosphere. In the tests a portion only of the steam was superheated. The steam pipes to and from the superheater are $3\frac{1}{2}$ inches diameter, and are provided with valves, which were kept full open. The main stop-valve on the boiler is 8 inches diameter, and was kept only 5–16ths inch open. The steam was taken to the superheater from underneath this valve, and the return pipe from the superheater was conducted direct to the main range of steam pipe supplying the engine. The temperature of the gases was not taken.

TABLE 2.—*Boiler Tests* WITHOUT *and* WITH *Musgrave and Dixon's Superheater.*
See Plate 33.

Dates of Tests.	Number of Tests. WITHOUT or WITH Superheater.	Mean Load.	Water evaporated per hour.	Coal burnt per hour.	Water evaporated per lb. of coal.	Water evaporated per I.H.P. per hour.	Coal burnt per I.H.P. per hour.	Degrees of Superheat.
1895.		I. H. P.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Fahr.
February 19–20	2 Without	303·55	5379·3	837·6	6·42	17·7	2·75	—
March 1–2	2 With	290·5	4706·3	667·2	7·06	16·2	2·29	42°
„ 5-6-7-8	4 With	298·06	4778·5	676·5	7·06	16·0	2·28	42°
„ 20–21	2 With	311·2	5141·1	734·7	7·00	15·5	2·35	55°
„ 26–27	2 Without	311·8	5492·1	914·0	6·00	17·6	2·92	—
Means	Without	307·67	5435·7	875·8	6·21	17·6	2·84	—
	With	299·45	4848·6	688·7	7·09	15·9	2·30	45·2°

Economy in Water per I. H. P. per hour 9·6 per cent. with superheating.
„ „ Coal „ „ „ „ 19 „ „ „ „

The engine is a horizontal tandem compound, fitted with Corliss valve-gear; cylinders $18\frac{1}{16}$ and $36\frac{1}{16}$ inches diameter by 4 feet stroke. Each of the tests was of $7\frac{1}{2}$ hours' duration.

The much easier working of the boiler for the same indicated horse-power at the engine is to be noted. During the tests of 20–21 March and 26–27 March the load was practically identical. In the former tests with superheating the rate of coal consumption was 18·8 lbs. per square foot of grate per hour, whereas in the latter tests without superheating the combustion went up to 23·4 lbs. of coal per square foot of grate per hour. Where there is a low and uncertain chimney draft, this slower combustion alone would tend to much steadier and more economical steaming, and would more than counterbalance any obstruction in the flues caused by the superheating pipes, which appears to be more imaginary than real.

McPhail and Simpsons' Superheater.—This apparatus is the invention of Mr. Hugh McPhail, and is manufactured in Wakefield by McPhail and Simpsons' Dry Steam Patents Co. It consists of two parts: the superheater proper; and the steam generator of radiating tubes, which distinguishes it from all other types. As applied to a Lancashire boiler, Plate 34, there are two nests of vertical steel tubes, expanded at top and bottom into cast-steel boxes, or "headers" as they are called in water-tube boilers; these nests are placed preferably at the back end of the internal flues of the Lancashire boiler, in the down-take, where the furnace gases impinge on them and pass between them. One of the top boxes is connected to the usual anti-priming pipe in the boiler; and the corresponding bottom box is connected to a block, which passes into the bottom of the boiler, and from which a copper pipe runs along the bottom of the boiler under the internal flues to the front end, and thence back again to the rear, where it passes out of the boiler and into the other bottom box. The second top box is connected to another copper pipe, which runs along the boiler over the internal flues, just below the water line, and ends at the main steam stop-valve. The course of the steam is from the anti-priming pipe to the first top box, then down through the superheating tubes

to the first bottom box, whence it enters the boiler, and passing through the lower copper pipe gives up part of its superheat to the surrounding water, before leaving the boiler and entering the second bottom box. It is then further superheated in passing up through the second nest of tubes; and thence passing through the second top box into the upper copper pipe in the boiler, it again parts with some of its superheat, before finally leaving the boiler at the steam stop-valve.

The complete apparatus thus consists of two external superheaters and two internal radiators; and the final degree of superheat depends upon the proportion of the superheating tubes to the radiating pipes. The function of these radiating pipes is most important, as they give off to the water in the boiler the superheat which might be dangerous in the engines at times of heavy firing; and, when the fires are green after cleaning and the flue gases low in temperature, they prevent any possibility of the superheater becoming a condenser. They thus tend to keep regular the amount of superheat in the steam as it leaves the boiler. It will be evident therefore that this superheater may be arranged either for improving the evaporative efficiency of a boiler and at the same time giving dry steam at the engine, or for the steam to leave the boiler highly superheated.

In its complete form this superheater has been tested and fully reported upon by several engineers in this country, among whom may be mentioned Messrs. Crosland and Michael Longridge. In Tables 3 to 5 are given the results of some recent tests, one made by M. Armengaud at the works of Messrs. Isaac Holden and Son, Reims, and others at Kinleith and Thornliebank, for which the author is indebted to the manufacturers.

The Reims tests, Table 3, were made before and after the apparatus was fixed on a Lancashire boiler 8½ feet diameter and 28 feet long with furnace tubes 3 feet 3¾ inches diameter. The heating surface is 1,012 square feet, and the grate area 39 square feet. The steam was used exclusively for a simple Corliss condensing engine with cylinder 28 inches diameter and 4½ feet stroke, running at 60 revolutions per minute, driving the machinery in a wool-combing mill. The work was arranged so that it should be as

nearly as possible equal on the occasion of each test. Owing to an oversight during the test made before the superheater was fixed, the feed was left on while the boiler fires were being cleaned, the usual custom being to raise the water level before cleaning and then stop the pump. The result was a fall in the steam pressure from 78 to 42½ lbs. per square inch ; and the boiler was so fully loaded that it took two hours to recover the normal pressure. The speed of the engine fell to 58 revolutions per minute, although the trips on the Corliss gear ceased to act and full steam was being taken for nearly an hour ; 59 revolutions per minute were made for a further half hour, before the usual speed was re-established. During the second test, after the superheater had been fixed, the same procedure was intentionally repeated, in order that both tests might be exactly compared ; the result was that the steam pressure fell only 3½ lbs., and the speed was not affected at all. This difference is most striking, and is a forcible proof of the great increase in the capacity of a boiler when fitted with the superheating apparatus. The superheat was measured at the boiler stop-valve, and was almost constant at 56° Fahr.

At Messrs. Henry Bruce and Son's, Kinleith Paper Mills, Currie, Midlothian, five Lancashire boilers are fitted with McPhail's apparatus. Their principal dimensions are 28 feet long by 7½ feet diameter ; heating surface 920 square feet, grate area 36 square feet ; working pressure about 90 lbs. absolute per square inch. In Table 4 is shown a test of the complete range of boilers, six without the superheaters against the five fitted with them.

At the works of the Thornliebank Co., near Glasgow, a Lancashire boiler is fitted with McPhail's apparatus. Its dimensions are 28 feet long and 8 feet diameter ; heating surface 955 square feet, grate area 39 square feet. One of their other boilers was tested against that fitted with the superheater, as shown in Table 5. The superheat of the steam leaving the stop-valve of the boiler fitted with the superheater averaged 56·2° Fahr. Since these tests were made, another boiler in the same set has been fitted with the same apparatus, and is producing steam at 80 lbs. per square inch above atmosphere and at 558° Fahr., being a superheat of 234° Fahr.

TABLE 3.

Boiler Test Without *and* With *McPhail and Simpsons' Superheater, at Messrs. Isaac Holden and Son's Wool-Combing Works, Reims. See Plate* 34.

Lancashire Boiler 28 feet long and $8\frac{1}{2}$ feet diameter, with two internal flues 3 feet $3\frac{5}{8}$ inches diameter; heating surface 1,012 square feet, grate area 39 square feet; supplying steam to a Corliss engine. Quality of fuel, Dourges.

	Without or With Superheater		Without	With
1	Date	1894	June 20	June 28
2	Duration of trial	hours	7·83	8
3	Average Boiler-Pressure per sq. inch above atm.	lbs.	73·6	91·5
4	Temperature corresponding with pressure	Fahr.	318·7°	331·6°
5	Temperature of Steam leaving boiler	Fahr.		388·1°
6	Degrees of Superheat	Fahr.	—	56·5°
7	Average Temperature of Feed-water	Fahr.	$117\frac{1}{2}$°	119°
8	Water evap., total during test	lbs.	49,899	47,096
9	„ „ per hour	lbs.	6,373	5,887
10	„ „ „ per sq. ft. of grate	lbs.	163·4	151·0
11	„ „ „ per sq. ft. of boiler heat. surf.	lbs.	6·29	5·81
12	Coal burnt, total during test	lbs.	7,364·7	5,435·3
13	„ „ per hour	lbs.	941	679·4
14	„ „ „ „ per sq. ft. of grate	lbs.	24·13	17·42
15	Ash and Clinker, total	lbs.	937	613
16	„ „ „ percentage of coal	per cent.	12·75	11·3
17	Combustible burnt, total	lbs.	6,427·7	4,822·3
18	Water evaporated per lb. of coal	lbs.	6·78	8·66
19	„ „ „ combustible	lbs.	7·76	9·76
20	Average Indicated Horse-power	I.H.P.	328·3	323·5
21	Coal per I.H.P. per hour	lbs.	2·86	2·10
22	Water „ „	lbs.	19·41	18·19
23	Gain in Coal per I.H.P.	per cent.	—	36·2
24	„ Water „	per cent.	—	6·7
25	„ „ evaporated per lb. of coal	per cent.	—	27·7
	Equivalent Evaporation from and at 212° Fahr.			
	Superheat neglected.			
26	Water per lb. of coal	lbs.	7·67	9·81
27	„ „ „	gain per cent.		27·9
28	„ „ combustible	lbs.	8·78	11·06
29	„ „ „ „	gain per cent.		25·8
	Superheat included.			
30	Water per lb. of coal	lbs.	7·67	10·07
31	„ „ „	gain per cent.		31·29
32	„ „ combustible	lbs.	8·78	11·35
33	„ „ „ „	gain per cent.		29·27

TABLE 4.—*Boiler Tests* Without *and* With *McPhail and Simpsons' Superheaters at Messrs. Henry Bruce and Son's, Kinleith Paper Mills, Currie, Midlothian.* *See Plate* 34.

Lancashire Boilers, each 28 feet long and 7½ feet diameter; heating surface 920 square feet, grate area 36 square feet. Quality of fuel, local Scotch coal.

	Without or With Superheaters.	WITHOUT				WITH				Gain due to Superheaters.
1	Number of test	1	2	3	Mean	4	5	6	Mean	Per cent.
2	Date of test 1895	July 2	July 3	July 4		Nov. 28	Dec. 4	Dec. 5		
3	Duration of test . . . . hours	9	9·16	9		8·75	9	9		
4	Number of boilers under test .	6	6	6		5	5	5		
5	Average Boiler-Pressure per sq. inch above atm. . lbs.	73·6	78	77·4	76·3	82	84·3	84·5	83·6	
6	Temperature corresponding with pressure . . . Fahr.	319°	322·5°	321·9°		325°	327·9°	327·5°		
7	Temperature of Steam leaving boilers . . . . . Fahr.					413°	421°	426°		
8	Degrees of Superheat . . Fahr.					88°	93·1°	98·5°	93·2°	
9	Average Temperature of Feed-water . . . . . Fahr.	116°	124°	118°		112°	106°	106°		
10	Water evaporated, total during test . . lbs.	393,095	315,581	371,610		392,410	420,867	413,375		
11	Water evaporated, per hour per boiler . . . . lbs.	7,280	6,288	6,882	6,817	8,969	9,352	9,186	9,169	34·5
12	Water evaporated, per hour per sq. ft. of grate . . lbs.	202	178	191		249	259	255		
13	Water evaporated, per hour per sq. ft. of boiler heat. surf. lbs.	7·91	6·83	7·48	7·41	9·75	10·16	9·98	9·96	

TABLE 4—(*continued*).

	Without or With Superheaters.		WITHOUT				WITH				Gain due to Superheaters.
	Number of test		1	2	3	Mean	4	5	6	Mean	Per cent.
14	Coal burnt, total during test	lbs.	57,792	53,256	56,817		47,452	49,423	47,544		
15	„ „ per hour per boiler	lbs.	1,070	969	1,052		1,084	1,098	1,056		
16	„ „ „ „ per sq. ft. of grate	lbs.	29·7	26·9	29·2		30·1	30·5	29·3		
17	Ash and Clinker, total during test	lbs.	7,071	6,741	7,479		5,096	5,520	5,024		
18	Ash and Clinker, percentage of coal	per cent.	12·23	12·65	13·16		10·73	11·16	11·81		
19	Combustible burnt, total	lbs.	50,721	46,515	49,338		42,356	43,903	42,520		
20	Water evaporated per lb. of coal	lbs.	6·802	6·489	6·541	6·611	8·269	8·515	8·694	8·493	28·4
21	Water evaporated per lb. of combustible	lbs.	7·750	7·428	7·532	7·570	9·264	9·586	9·721	9·524	25·8
	Equivalent Evaporation from and at 212° Fahr.										
	Superheat neglected.										
22	Water per lb. of coal	lbs.	7·704	7·306	7·404	7·471	9·418	9·758	9·963	9·713	29·9
23	„ „ „ „ combustible	lbs.	8·788	8·365	8·526	8·557	10·552	10·985	11·140	10·892	27·2
	Superheat included.										
24	Water per lb. of coal	lbs.				7·471	9·790	10·158	10·406	10·121	35·4
25	„ „ „ „ combustible	lbs.				8·557	10·968	11·436	11·636	11·350	32·6

TABLE 5 (*continued on opposite page*).

Boiler Tests Without *and* With *McPhail and Simpsons' Superheater, at the Thornliebank Co.'s Works, Thornliebank, Glasgow.*
See Plate 34.

Lancashire Boilers, Nos. 6 and 7, each 28 feet long and 8 feet diameter; heating surface 955 square feet, grate area 39 square feet.
Quality of fuel, Greenfield Virgin Coal. No. 7 boiler had Superheater attached.

	Number of Test	1	
	Date of Test . . . 1895	Aug. 28	
	Duration of Test	8 hours	
	Fireman	Lowry	
	No. 6 boiler Without and No. 7 boiler With Superheater	Without	With
1	Average Boiler-Pressure per sq. inch above atm. . . . lbs.	72	72
2	Temperature corresponding with pressure . . . Fahr.	317·8°	317·8°
3	Temperature of Steam leaving boiler . . . Fahr.	309·3°	373°
4	Degrees of Superheat . . . Fahr.		55·2°
5	Average Temperature of Feed-water . . . Fahr.	161°	156°
6	Water evaporated, total during test . . . lbs.	58,910	69,586
7	" " gain due to Superheater . . . per cent.		18·1
8	Water evaporated per hour . . . lbs.	7,363	8,698
9	" " " " per sq. ft. of grate . . . lbs.	188·8	223·0
10	" " " " per sq. ft. of boiler heat. surf. lbs.	7·71	9·10
11	Coal burnt, total during test . . . lbs.	9,632	9,632
12	" " per hour . . . lbs.	1,204	1,204
13	" " " " per sq. ft. of grate . . . lbs.	30·8	30·8
14	Ash and Clinker, total . . . lbs.	1,397	1,596
15	" " " percentage of coal . . . per cent.	14·5	16·5
16	Combustible burnt, total . . . lbs.	8,235	8,036
17	Water evaporated per lb. of coal . . . lbs.	6·11	7·22
18	" " " " combustible . . . lbs.	7·15	8·65
	Equivalent Evaporation from and at 212° Fahr. *Superheat neglected.*		
19	Water per lb. of coal . . . lbs.	6·63	7·88
20	" " " combustible . . . lbs.	7·76	9·44
21	Gain due to Superheater (on combustible) . . . per cent.		21·64
	Superheat included.		
22	Water per lb. of coal . . . lbs	6·63	8·09
23	" " " combustible . . . lbs.	7·76	9·69
24	Gain due to Superheater (on combustible) . . . per cent.		24·87

(*concluded from opposite page*) TABLE 5.

Boiler Tests Without *and* With *McPhail and Simpsons' Superheater, at the Thornliebank Co.'s Works, Thornliebank, Glasgow.*
See Plate 34.

No. 7 boiler with Superheater did 12·97 per cent. more work, or in other words the saving effected was 19·08 per cent.
owry being the regular fireman and acquainted with the boilers obtained the best results.

	2 Aug. 29 8 hours Parker		3 Sep. 5 8 hours Hannah		4 Sep. 6 8 hours Lowry		5 Sep. 10 8·66 hours Parker		Average Gain due to Super-heater. Per cent.
	Without	With	Without	With	Without	With	Without	With	
1	72·5	72·5	57	57	58	58	63	63	
2	318°	318°	304·8°	304·8°	305·7°	305·7°	310°	310°	
3	304°	372°	303·8°	363·9°	300·1°	366·5°	300°	362°	
4		54°		59·1°		60·8°		52°	
5	161·5°	155°	145·6°	151·0°	148·5°	153°	146°	151°	
6	68,978	76,181	55,890	62,040	55,277	65,600	70,684	75,461	
7		**10·4**		**11·0**		**18·6**		**6·75**	**12·97**
8	8,622	9,522	6,986·2	7,754·7	6,909·6	8,200	8,162	8,713	
.9	221·1	244·2	179·1	198·8	177·2	210·3	209·3	223·4	
10	9·02	9·97	7·31	8·12	7·23	8·58	8·57	9·12	
11	10,976	11,200	9,086	9,171	9,408	9,408	10,752	10,304	
2	1,372	1,400	1,135·7	1,146·4	1,176	1,176	1,241	1,189	
3	35·1	35·9	29·1	29·3	30·1	30·1	31·8	30·5	
4	1,364	1,572	1,252	1,486	1,428	1,521	1,276	1,292	
5	12·4	14·0	13·7	16·2	15·1	16·1	11·8	12·5	
6	9,612	9,628	7,834	7,685	7,980	7,887	9,476	9,012	
7	6·28	6·80	6·15	6·76	5·87	6·97	6·57	7·32	
8	7·17	7·91	7·13	8·07	6·92	8·31	7·45	8·37	
9	6·81	7·42	6·69	7·38	6·42	7·59	7·22	8·00	
0	7·77	8·64	7·82	8·81	7·57	9·05	8·18	9·15	
1		**11·2**		**12·6**		**19·5**		**11·8**	**15·35**
2	6·81	7·70	6·69	7·59	6·42	7·84	7·22	8·24	
3	7·77	9·00	7·82	9·06	7·57	9·34	8·18	9·42	
4		**15·83**		**15·85**		**23·38**		**15·16**	**19·08**

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This type of superheater was adopted by the author in 1893 at the Maiden Lane station of the Charing Cross and Strand Electricity Supply Corporation, but had to be considerably modified to suit the Babcock and Wilcox water-tube boiler, as it was found possible to put only one set of superheating tubes in the limited space between the top of the water tubes and the underside of the drum, and only one set of radiating pipes in the drum: so that the arrangement represents only one half of the complete apparatus as applied to a Lancashire or double-flued boiler. The arrangement is shown in Plate 35. The saturated steam is taken from the anti-priming pipe to the upper box of the superheater, whence it passes down through the superheating tubes to the lower box, thence up into the radiating pipes in the drum, and through these to the steam stop-valve. The principal dimensions of the Babcock and Wilcox boiler are:—$9 \times 9 = 81$ tubes, 18 feet long and 4 inches diameter; total heating surface about 1,827 square feet; drum $23\frac{1}{2}$ feet long and 4 feet diameter; width of fire-grate 5 feet 6 inches; total grate surface 34·4 square feet. The principal dimensions of the superheater are:—75 superheating tubes of 1 inch diameter, heating surface 355 square feet; 12 radiating pipes of 2 inches diameter, heating surface 174 square feet; area through superheating tubes 58·9 square inches, through radiating pipes 37·7 square inches, and through steam stop-valve 28·27 square inches.

Complete tests of one boiler were made by Professor Kennedy, before and after the superheating apparatus was fixed; and the principal results are given in Table 6. The dynamos are Edison-Hopkinson continuous-current shunt-wound, driven by Willans engines.

The great increase in the capacity of the boiler will be noted in line 8; the steaming was much easier and steadier, and at the same time the efficiency of the boiler improved from 68·4 per cent. to 74·9 per cent. (line 29), and this with cold feed. Practically the whole of the superheat was lost in the range of steam-pipes between the boiler and engine. The slight difference in water used per kilo-watt hour may be accounted for by the engine not being in such good order in the second test as in the first. It had been thoroughly overhauled

TABLE 6.

Boiler Tests Without *and* With *McPhail and Simpsons' Superheater.*
See Plate 35.

			Without	With
	Without or With Superheater . . .	. .	Without	With
1	Date of trial	1893	June 20	Oct. 17
2	Duration of trial, hours and minutes .		8–15	8–31
3	Indicated Horse-power of engines working at full load . . .	I.H.P.	135	135+80
4	Full output of Dynamos, ampères × volts		$750a \times 105v$	$\begin{cases}750a \times 105v \\ 450a \times 105v\end{cases}$
5	Coal burnt, total	lbs.	3,229	4,528
6	„ „ per hour	lbs.	389	532
7	Water pumped into boiler, total . .	lbs.	28,000	43,655
8	„ „ „ „ per hour .	lbs.	3,457	5,125
9	Mean Electrical Horse-power . .	E.H.P.	82·15	129·2
10	Total Kilo-watt hours (units) . .		686·4	824·2
11	Mean Kilo-watts		61·3	97·0
12	Boiler Pressure above atm., per sq. inch	lbs.	131·3	140·3
13	Mean Temperature of steam on leaving boiler	Fahr.	355°	377·1°
14	Mean Temperature of saturation at boiler pressure	Fahr.	355°	361·0°
15	Mean Temperature of steam in engine-room steam-pipes	Fahr.		365·1°
16	Mean Temperature of saturation at probable pressure in engine-room steam-pipes	Fahr.		358·3°
17	Mean Temperature of Feed-water . .	Fahr.	80·4°	79·76°
18	Calorific value of 1 lb. of coal . .	Th. U.	14,840	14,790
19	Equivalent Evaporation per lb. of coal .	lbs.	15·36	15·31
20	Carbon value of coal per lb. . . .	lbs.	1·023	1·020
21	Actual Water evaporated per lb. of coal	lbs.	8·89	9·65
22	Evaporation per lb. of coal from and at 212°	lbs.	10·50	11·47
23	Evaporation per lb. of carbon value .	lbs.	10·30	11·22
24	Coal burnt per hour per sq. foot of grate	lbs.	11·3	15·5
25	„ „ „ „ per E.H.P. . .	lbs.	4·74	4·12
26	Water per hour per E.H.P.	lbs.	42·1	39·7
27	Coal per kilo-watt hour . . .	lbs.	6·35	5·5
28	Water „ „ „ „	lbs.	56·4	52·8
29	Efficiency of boiler, 100 × line 22 ÷ line 19 . .	per cent.	68·4	74·9
30	Temperature of gases leaving boiler .	Fahr.	309°	376°
31	Mean chimney draught, inch of water .	inch	0·3	0·4

immediately before the June trial, and had been in daily use from that date until the October trial, so that both valve and piston-rings would be somewhat slacker in October than in June. The same

TABLE 7.

Steam Tests Without *and* With *McPhail and Simpsons' Superheaters.*

See Plate 35.

Without or With Superheaters.		Without.		With.		
Boiler Pressure, absolute,	lbs. per square inch	166	168	157	162	162
Corresponding Temperature of saturated steam,	Fahr.	366·5	367·0	362·0	361·5	364·5
Temperature in main steam-pipe in engine-room,	Fahr.	359	361	371	375	373
Fall or Rise in temperature of steam,	degrees Fahr.	− 7·5	− 6·0	+ 9·0	+ 10·5	+ 8·5

cause would affect the coal consumption, which nevertheless shows a saving of 13·5 per cent.

The increased capacity and ease in working of the boiler have been as marked in its subsequent use with the superheating apparatus; in regular work it is evaporating about 50 per cent. more than heretofore. At first the author had some misgivings as to incrustation forming in the superheating tubes from the priming water; but from examining them closely on several occasions after a run of 4,000 hours and more, and finding them perfectly clean, he is satisfied on this point. The top box, by its increase in area over the steam-pipe, gives a period of comparative rest in the flow of the steam, and acts as an efficient separator for the water or scum carried over. A steam trap fitted to the box discharges any such accumulation regularly, thus preventing its being carried into the superheating tubes. The bottom box is also fitted with a trap to intercept any leakage from the steam stop-valve when the boiler is shut in.

The first apparatus proved so satisfactory that a second was applied to the companion boiler in 1894, when the effect of the superheated steam in the pipes began to be marked by a decrease in the discharge from the drains and in the leakage from joints. There are altogether seven boilers, of which five or six are in general use on a common steam-main. The figures in Table 7 show this effect clearly.

Induced Draught.—The duty of the boilers having been increased to the above extent, and the priming difficulty being quite overcome, the only limit to the evaporation was the chimney draught. As the two boilers were fitted with an independent flue and chimney, they lent themselves readily to an experiment in this direction. Having considered several schemes of forced and induced draught as an auxiliary, the author finally decided on putting a fan in the flue at the back of the boilers. As there was no space available for any form of economiser between the boilers and the fan, no attempt could be made to diminish the loss from heat in the waste gases. The gain sought for was in the direction of increasing the capacity of the existing boilers, so as to render steaming independent of the

natural effects of foggy or heavy weather, and by working the boilers at a higher rate to diminish the proportion of radiation losses, which are practically constant at all loads.

The fan selected is a 72-inch single-inlet, made by Messrs. G. E. Belliss and Co., and driven direct by one of their tandem compound self-lubricating engines, having cylinders $3\frac{1}{2}$ and 6 inches diameter and $4\frac{1}{2}$ inches stroke, working at 150 lbs. boiler pressure, and running at 300 revolutions per minute. The engine and fan were put in somewhat large for the estimated work, in order to secure slow speed and quiet running, with the result that within a few feet of the fan it is impossible to tell by the sound whether it is running or not; this is a marked improvement on many fan-engines. A draught in the flue at the fan inlet equal to a 2-inch water-gauge has been easily maintained. The usual method of working is to work the boilers on natural draught at times of light load; and then, as the load increases, to start the fan, close the by-pass in the flue, and work steadily at 1-inch water-gauge. With this draught the superheater tubes are continually bathed in incandescent gases, but not the slightest trouble has been experienced with them. In order to test the thorough reliability of the tubes, and in view of the fact that trouble was most likely to arise, if at all, when getting up steam, one of the boilers was shut in, and the steam let down day after day for some weeks, and then raised again with the induced draught; and there was an entire absence of any signs of irregularity or trouble.

When the boiler is steaming freely, an iron bar inserted through the brickwork to a point near the ends of the tubes soon becomes red-hot; and the temperature as taken by a platinum-coil pyrometer at this point is about 900° Fahr. At this temperature it appears to be of little importance whether the cooling agent is water or steam, so long as the circulation is kept up. This circumstance is most interesting in view of Mr. Durston's Devonport experiments, reported in his presidential address to the Institute of Marine Engineers,* as to the permissible limit of temperature in a tube or tube-plate, which he places at about 750° Fahr.; and in view also of

* "Engineering," 4 October 1895, page 437. See also Transactions of the Institution of Naval Architects, 1893, vol. xxxiv, page 132.

the grave doubts that are frequently expressed as to the safety of steel tubes exposed to furnace temperatures without a perfect circulation of water on the other side of the metal. What temperature the tubes actually reach the author is unable to state; but the steam coming out of them is over 600° Fahr. The tube-plates would be lower in temperature than the outer ends of the tubes, because the gases are drawn downwards and away from the plates by the draught. No trace of leakage at any one of the tube ends has yet appeared.

A further test of the boiler with the induced draught was made on 2nd January 1896. It was not possible to shut off part of the steam ring-main, and to use the steam on certain steam-dynamos only, measuring the electrical output from them, as had been done in the two former tests; an evaporative test only was therefore arranged for. The stop-valve temperature was measured about five feet from the stop-valve at the boiler, on a branch pipe about ten feet long, connecting the boiler with the main ring. A mercury thermometer in a mercury cup let into the steam-pipe was used in this position. Being anxious to get the temperature of the steam between the superheater and the radiating pipes in the drum, the author had tried mercury thermometers, which failed. The difficulties due to the high pressure and temperature were successfully overcome however by Mr. Frederic W. Burstall, to whose ingenuity and kindness in co-operation the author is indebted in this matter. With a temperature of 1,058° around the superheating tubes, steam entering at 362° left them at 650°, and after passing through the radiating pipes in the drum left the boiler at 403° Fahr. The principal results are given in Table 8 (page 156), the boiler being fired with Welsh steam coal. It will be noted that the application of the superheater together with a stronger draught has increased the capacity of the boiler by 140 per cent., or raised the evaporation from 3,457 lbs. per hour (Table 6) to 8,294 lbs. without increasing the space occupied: which is a most important gain, and a saving both in capital and in rent. In comparing the temperature here given of the gases leaving the boiler with those given in Table 6, it should be noted that in Table 8 the temperatures were taken between the back

TABLE 8.—*Test of Babcock and Wilcox Boiler fitted with McPhail and Simpsons' Superheater.* *See Plate* 35.

Date of Trial	1896	Jan. 2.
Duration of Trial	hours	8
Coal burnt, total	lbs.	8.050
,, ,, per hour	lbs.	1,006·25
Ash and Clinker, dry	lbs.	476
Water evaporated, total	lbs.	66,350
,, ,, per hour	lbs.	8,294
Boiler Pressure above atm. per square inch . . .	lbs.	145·3
Temperature corresponding with pressure . . .	Fahr.	363·4°
Mean Temperature of Steam at stop-valve . . .	Fahr.	400·8°
Degrees of Superheat	Fahr.	37·4°
Mean Temperature of Feed-water	Fahr.	48°
Actual Water evaporated per lb. of coal . . .	lbs.	8·24
,, ,, ,, ,, ,, ,, combustible . .	lbs.	8·76
Water evaporated per lb. of coal from and at 212° F. .	lbs.	10·16
,, ,, ,, ,, ,, combustible ,, ,, ,, .	lbs.	10·84
Coal burnt per sq. ft. of grate per hour. . . .	lbs.	29·25
Water evaporated per sq. ft. of heating surface per hour .	lbs.	4·37
Temperature of gases leaving boiler	Fahr.	654°
Mean chimney draught, inches of water . . .	inch	1·11

tubes and the wall in which is situated the damper communicating with the flue. In Table 6 the temperatures were taken in the flue, where the gases are cooled by the influx of cold air through the damper slots, and by any leakage through the other boiler, which was shut off at the time.

Schwoerer's Superheater.—The superheater illustrated in Plates 36 and 37 is the invention of Mr. Emile Schwoerer of Colmar, Alsace, who was for some time private secretary to the late Mr. G. A. Hirn. It was Mr. Hirn who first took up superheating seriously; and it is due to his energy that so much has been done with it in practical working in Alsace. Mr. Schwoerer's improvements were in the direction of reducing the space occupied by the apparatus; and he attained this end by employing a coil of pipes with gills on them both inside and outside, thus getting large surfaces in a small bulk. Regulation of

TABLE 9.—*Boiler Tests* Without *and* With *Schwoerer's Superheaters.*

See Plates 36 *and* 37.

Tests made by	Mr. Walther Meunier.								Professor Unwin.			
No. of Test	1	2	3	4	5	6	7	8	9	10	11	12
Without or *With* Superheaters	*Without*	*With*	*Without*	*With*	*Without*	*With*	*Without*	*With*	*Without*	*With*	*With*	*With*
Number of Boilers in use	3	2	4	3	4	3	1	1	4	3	3	3
Duration of trial, hours and minutes	11–10	11–0	10–24	10–19	11–50	11–30	11–30	11–30	6–0	5–0	6–0	5–0
Mean Indicated Horse-power	278	276	554	564	310	309	116	119	475·0	491·0	501·4	502·3
Steam per I.H.P. per hour lbs.	19·8	17·1	21·87	17·44	19·00	15·70	21·6	19·2	19·75	15·63	17·06	15·61
Coal „ „ „ lbs.	3·14	2·36	3·78	3·01	2·98	2·38	3·45	2·64	3·147	2·593	2·564	2·513
Boiler Pressure above atm., per square inch lbs.	80	68·4	86·7	86·7	68	65	68	68	95·72	99·05	93·74	94·00
Superheat Fahr. at apparatus	—	150°	—	135°	—	171°	—	191°	—	177·7°	181·1°	188·6°
Superheat Fahr. at engine	—	115°	—	102°	—	118°	—		—	118·3°	119·2°	126·9°
Economy in Steam, per cent.	—	13·6	—	20	—	17·4	—	11·0	—	20·9	13·6	20·9
„ Coal, per cent.	—	25	—	20	—	20·1	—	23·5	—	17·6	18·5	20·1

the superheat by deflecting the hot gases away from the tubes, rather than by varying the proportion of the total steam passing through the tubes, is due to Mr. Schwoerer: though this regulation does not appear to have been generally carried out. By the courtesy of Professor W. Cawthorne Unwin the author is enabled to give the tests in Table 9 (page 157) of Schwoerer superheaters in Alsace, some of which were carried out by himself and others by Mr. Walther Meunier, engineer-in-chief of the Alsatian Association of Steam Users. It will be noted that in tests 1, 3, 5, 9, one more boiler was required to do the work when saturated steam was being used at the engine. The boilers were of the elephant kind, with Green's economisers.

An application of the Schwoerer superheater has been made by Messrs. James Simpson and Co. to a Babcock and Wilcox water-tube boiler at the Grand Junction Water Works, Kew Bridge.* The arrangement is shown in Plates 36 and 37. The boiler is of the same size as those fitted by the author with McPhail's apparatus at Maiden Lane. Full details of the trials unfortunately cannot be obtained; but the saving effected is satisfactory. Tests were conducted by Mr. Osbert Chadwick before and after the superheater was fixed, with the following results, Table 10.

TABLE 10.

Boiler Tests Without *and* With *Schwoerer's Superheater.*
See Plates 36 *and* 37.

Date	21 Jan. 93	20 Dec. 93	22 Feb. 94	13 Mar. 94
Degrees of Superheat, Fahr.	0°	57·7°	109·5°	57·0°
Steam per Pump H.P. per hour, lbs.	20·98	19·71	18·75	19·48
Saving effected, per cent.		6·05	10·63	6·75

A test was also conducted by Mr. Goodman, the Superintending Engineer at the pumping station, under ordinary working conditions from 8 December 1894 to 5 January 1895, the engine and boiler being kept continually at work. The fuel used was 86·98 per cent. anthracite peas and 13·02 per cent. breeze, the draught being assisted by a Meldrum blower. The results then obtained were :—

* "Engineering," 29 March 1895, page 403.

Duration of trial	723½ hours
Feed-Water per hour	3223 lbs.
Fuel per hour	471 lbs.
Steam per Pump Horse-power per hour .	17·74 lbs.
Fuel " " " " " " .	2·58 lbs.
Mean Superheat	121° Fahr.

These results showed a saving of about 15 per cent. on what had been obtained before the Schwoerer superheater was fixed.

This type of superheater is also made by Messrs. Fraser and Chalmers, Erith, who have one in constant use at their works.

Sinclair's Superheater.—Another form of superheater is shown in Plate 38, which is due to Mr. George Sinclair of Leith. There is here a departure from the usual method of securing the tubes, which in this apparatus are flanged and bolted to the cross inlet and outlet pipes, instead of being expanded into them. In such positions an expanded joint is generally considered desirable; but here the joints are removed from the action of the hot gases, and a bolted joint gives much greater facilities for removing a tube in order to examine or clean it. In Plate 38 the apparatus is shown in conjunction with a marine dry-back boiler, as fitted by Professor Kennedy at the Edinburgh Electric Lighting Station. The arrangement is very compact, and should prove highly economical. The hot gases from the smoke-box at the front are led to the back over the top of the boiler, passing among the superheating tubes; thence down the sides of the boiler to the centre flue underneath it. The apparatus was described in Mr. Burstall's paper read at the last Autumn Meeting (Proceedings 1895, page 552), and in the discussion Professor Kennedy stated that further tests were then in hand; the author would be very glad if the present should be considered a convenient opportunity for publishing the results of them. [See Table 12, page 166.]

It is much to be regretted that so little has been done as yet with superheated steam at the engine. In nearly every instance the superheat appears to be gone, if not at the steam-chest, at any rate immediately on admission to the cylinder. But even under these

circumstances the advantage of superheating is manifest from many of the tests given above; and it must be recognised that, although the steam may be cooled down again to the temperature corresponding with the pressure, it is still dry steam, and is a better working gas than the saturated solution of water-dust supplied by an ordinary boiler. The desirable amount of superheat has been generally considered to be the equivalent of the heat lost by initial condensation; but this does not obtain in practice. The amount of heat lost in initial condensation is generally from 20 to 25 per cent. of the total heat of the steam above boiling point. Tests with superheated steam show a saving of 20 per cent. with only 5 per cent. extra heat in the steam. This point has been brought out clearly by Mr. W. H. Booth in his paper on cylinder condensation, read to the Manchester Association of Engineers on 26th October 1895, wherein it was shown that the amount of superheat is but little in excess of that necessary to supply the heat required for making good the latent heat which disappears as work during expansion.

When preparing to respond to the request that he would contribute a paper giving his own experience with superheating, the author found that, although a great deal had been done, but little information on this subject was to be met with in the Institution Proceedings. He has therefore endeavoured to the best of his ability, during a particularly busy winter, to fill up the blank by collecting and recording all the data that he is himself possessed of. It is not imagined that the superheaters here described make up a complete list; and it is hoped that any which have not been included in the paper will be dealt with to better advantage by speakers in the discussion. The theory and advantages of superheating at the engine have not been touched upon, not only for want of space, but also in the hope that some member of the Institution who has given the subject much attention may be tempted to contribute a comprehensive paper thereon. In conclusion the author desires to thank the several gentlemen and firms who have kindly given him information and plans.

Discussion, 31 January 1896.

Mr. Patchell said that in the test reported in Table 1 (page 139) of a Gehre superheater he could not understand how the evaporation per lb. of coal could go up from 7·82 lbs. without the superheater to 9·99 lbs. with the superheater. The test had been made in Germany, and these were the original figures supplied to Mr. Donkin; and he had not been able to obtain any further information about them. If a boiler was hard worked, the addition of a superheater might improve the evaporation slightly, because the engine working with superheated steam would take less steam; consequently the boiler would have to evaporate less, and the efficiency might thereby be slightly increased; but he should not expect quite so large a difference as was shown in Table 1.

The tests reported in Table 9 (page 157) of Schwoerer superheaters could now be supplemented by the later tests given in Table 11 (pages 162–3), which Mr. Schwoerer had been good enough to send, and in which it would be seen that the superheat had gone up considerably—to as high as 251° Fahr. These higher degrees of superheat were naturally those measured at the boiler or superheater, not at the engine. The economy of coal was seen to range from 19·8 up to 28·6 per cent. in Mr. Meunier's tests; while it was only 16·5 per cent. in the test made by Mr. Isambert, who was the engineer-in-chief of the Baden Association of Steam Users at Mannheim.

With the boilers in Maiden Lane, since making the test on 2nd January described in the paper (pages 155–6), he had made two further tests, mainly for the purpose of trying the stokers one against the other. Each man fired the same boiler, and each test lasted eight hours. One stoker got an average evaporation of 8,758 lbs. of water per hour, but the water evaporated per lb. of coal went down to 7·9 lbs. The other stoker appeared to be the best, getting an average evaporation of 10,125 lbs. of water per hour, while the water evaporated per lb. of coal was 8·3 lbs., or slightly more than the 8·24 lbs. given in Table 8 (page 156). When it was

(*continued on page* 164.)

(Mr. Patchell.)

TABLE 11.—*Boiler Tests* Without *and* With *Schwoerer's Superheaters.*

See Plates 36 and 37.

Tests made by	Mr. Walther Meunier.							
No. of Test	13	14	15	16	17	18	19	20
Without or *With* Superheaters	*Without*	*With*	*Without*	*With*	*Without*	*With*	*Without*	*With*
Number of Boilers in use	2	2	5	4	7	6	2	1
Duration of trial, hours and minutes	10–57	10–2	10–46	10–49	11–0	11–0	12–0	12–0
Mean Indicated Horse-power . . . I.H.P.	134·4	133·5	447·4	441·5	573·5	596·1	277·4	276·5
Steam per I.H.P. per hour . . . lbs.	22·5	20·2	21·0	17·6	27·9	22·3	18·4	14·6
Coal " " " " . . . lbs.	4·31	3·48	4·97	3·90	4·01	3·10	2·07	1·64
Boiler Pressure above atm., per square inch lbs.	70·0	68·8	84·3	85·5	52·7	58·5	71·0	71·0
Degrees of Superheat . . . Fahr.	—	122·0°	—	141·1°	—	136·4°	—	204·0°
Economy in Steam . . . per cent.	—	10·0	—	18·2	—	20·0	—	20·7
" " Coal . . . per cent.	—	19·8	—	21·6	—	22·5	—	21·0

TABLE 11 (*continued*).

Tests made by	Mr. Walther Meunier.						Mr. Isambert.	
No. of Test	21	22	23	24	25	26	27	28
Without or *With* Superheaters	*Without*	*With*	*Without*	*With*	*Without*	*With*	*Without*	*With*
Number of Boilers in use	1	1	6	4	6	3	4	4
Duration of trial, hours and minutes	11–3	11–4	11–0	11–0	11–0	11–0	3–13	3–30
Mean Indicated Horse-power I.H.P.	104·0	129·0	768·0	789·0	759·8	776·1	570·2	524·8
Steam per I.H.P. per hour lbs.	30·5	22·8	16·2	13·8	16·7	13·3	14·5	11·8
Coal ,, ,, ,, ,, lbs.	5·28	3·91	3·29	2·45	2·40	1·71	1·91	1·59
Boiler Pressure above atm., per square inch lbs.	70·7	72·8	81·2	81·2	80·8	81·5	95·3	94·4
Degrees of Superheat Fahr.	—	243·0°	—	189·0°		251·6°	—	142·0°
Economy in Steam per cent.	—	25·1	—	15·0	—	20·5	—	18·3
,, ,, Coal per cent.	—	**25·9**	—	**25·2**	—	**28·6**	—	**16·5**

(Mr. Patchell.)
considered that this was nearly three times what the boilers had originally been doing, he thought it spoke well both for the superheating apparatus and for the stokers.

Professor Alexander B. W. Kennedy, Past-President, said it had been mentioned by Professor Barr on the previous evening that while President he had been to some extent responsible for getting the paper on the range-finder. He had also been responsible for asking Mr. Patchell for the present paper; and if he had done nothing else during his two years of office than obtain these two papers for the Institution, he should be happy to think he had been instrumental in conferring some permanent benefit on the Members.

In the discussion on the Edinburgh electric lighting station at the last meeting the question of superheating had come up in connection with the superheaters there used; he had then promised that, as soon as he had any information to give, he would lay it before the Institution. He had now particular pleasure in doing so in connection with the mass of useful information given in the present paper. At the previous meeting he had mentioned that he was not able to report having got much superheating up to that time: which he had then attributed to a small extent to errors in the thermometers, and to a large extent to the want of proper covering on the superheaters. That explanation however he had found was not quite correct: the unsatisfactory figures obtained were only to a small extent due to the want of proper covering on the superheaters, but to a very large extent to the great difficulty of getting the thermometers to read rightly under the circumstances, which had altogether misled him for a considerable time. The difficulty was partly got over by a special treatment of the mercury thermometers, which after a while could be read with reasonable accuracy; and was finally got over altogether by the use of platinum thermometers designed by Mr. Burstall, which had proved highly successful. These instruments he hoped Mr. Burstall would himself describe later on in the discussion; so that he need not enter into any description of them at present. A great many experiments had been made with the Edinburgh superheaters, which had been in continuous

use since April last. As however the superheaters had been continuously in use, it was not easy to get comparative figures as to their benefit; but during the previous week he had got one engine and one boiler isolated, all the rest of the steam pipes being shut off, and he ran that particular boiler and engine on one day with the superheater and on one day without. The figures so arrived at might be taken as being exact, because everything could be accurately measured. From Mr. Monkhouse, the resident engineer of the station, he had also received the actual figures of 24 hours' working of the whole station with and without the whole of the superheaters. These latter figures were of course just the result of whatever happened to be the state of things at the time, and therefore they were not so exact as the others. He rather thought they were unduly unfavourable to the superheaters; but anyhow he had much pleasure in giving the four sets of figures. In the 24 hours' trial without superheating, the consumption of feed-water was 52·1 lbs. per kilowatt-hour; and on the previous day, with superheating, it was 47·6 lbs., showing a saving in steam of about 9 per cent. During the same time the coal consumption per kilowatt-hour was 6·5 lbs. without superheating, and 5·8 lbs. with, showing a saving of about 11 per cent. The difference in coal was an indirect result which could here be accounted for without any of the difficulty that was naturally experienced in the case mentioned by Mr. Patchell in page 161. It might be said therefore that during a reasonably accurate test of 24 hours' work there was a saving of roughly 10 per cent. by superheating. By taking the more exact measurements which could be made in running a single engine at full power during the whole day separately from the main circuit, the following figures had been obtained, as shown in the accompanying Table 12 (page 166):—without any superheating, the consumption of feed-water was 42·2 lbs. per kilowatt-hour; while with an amount of superheating which averaged 65° Fahr. at the engine, the consumption was reduced to 32·7 lbs. of water. At the same time, owing to the better working of the boiler, and more particularly to the fact that the dampers could be handled better, and the proportion of carbonic acid be thereby increased in the

(Professor Alex. B. W. Kennedy.)

TABLE 12.—*Edinburgh Electric Lighting Station. Boiler and Superheater Tests.*

	WITHOUT OR WITH Superheaters *See Plate 38.*		WITHOUT	WITH		WITH	WITHOUT
1	Date	1896	Jan. 23	Jan. 24		Jan. 27–28	Jan. 28–29
2	Duration of test	hours	about 4	about 5		24	24
3	Coal burnt, total during test (uncorrected)	lbs.				31,920	34,440
4	Water evaporated, total during test	lbs.				255,900	268,400
5	Kilowatt-hours, total					5,372	5,148
6	Coal burnt per hour	lbs.	750	615		1,330	1,435
7	Moisture in coal (about)	per cent.	3	3		3	3
8	Dry Coal burnt per hour	lbs.	727	595		1,290	1,392
9	,, ,, ,, per kilowatt-hour	lbs.	5·05	3·99		5·77	6·49
10	Grate surface	square feet	16	16			
11	Coal burnt per square foot of grate per hour	lbs.	47	38·4			
12	Carbonic acid in furnace gases, by volume	per cent.	3·87	5·1			
13	Temperature in smoke-box	Fahr.	633°	581°			
14	,, in superheater	Fahr.	428°	432°			
15	Draught, inch of water	inch	0·53				
16	Superheat (about)	Fahr.	none	30°	65°		none
17	Evaporative value of Coal, calculated	lbs.	13·0	13·0	13·0	13·0	13·0
18	Water evaporated per hour	lbs.	6,050	5,520	4,890	10,662	11,183
19	Average Steam-Pressure (about) } boiler house	lbs.	156	158			
20	per square inch above atm. } engine room	lbs.	154	158			
21	Water evaporated per kilowatt-hour	lbs.	42·2	37·2	32·7	47·6	52·1
22	,, ,, per electric horse-power	lbs.	31·3	27·7	24·5		
23	,, ,, per lb. of dry coal, actual	lbs.	8·07	8·57		8·27	8·03
24	,, ,, ,, ,, ,, from and at 212° Fahr.	lbs.	8·57	9·32			
25	Boiler Efficiency (* including superheater)	per cent.	65·8	*71·8			
26	Kilowatts, average		143·6	148·5	149·0		
27	Electric Horse-power, average	E.H.P.	193	199	199·5		
28	Dry Coal burnt per electric horse-power hour	lbs.	3·78	2·99			
29	Temperature of Feed-water (say)	Fahr.	200°	200°			
30	Factor of Evaporation, line 24 ÷ line 23 (*including superheater)	approximate	1·06	*1·087			

furnace gases, the evaporation was raised from 8·6 lbs. of water per lb. of coal to 9·3 lbs. of water under standard conditions, the coal being only small washed nuts, not the Welsh coal of ordinary trials. These figures corresponded with a difference of about 22 per cent. in favour of superheating, which was a very important saving. At times of full load the superheat at the boilers ran up to 80° and 85°, the average being about 70° to 75° at the boilers; and practically this amount of superheat was actually gained in the steam-chests of the engines nearest to the boilers,* while the superheat dropped to about 48° on the side of the engine-room furthest away from the boilers. There was therefore no doubt that he had really succeeded in getting substantial superheat at every engine throughout the whole engine-room. But it was interesting to note that, when the average superheat at the engine was reduced to 30°, the saving in steam per kilowatt-hour was only 11 per cent., as against 22 per cent. when the superheat had been 65° at the engine: so that it was clear that 65° of superheat was not in the least too high. Put in another form, the result was simply this:—the particular engine experimented on was a Willans non-condensing compound machine, which when it was tested at the makers' works at Thames Ditton, with the steam measured as it came out of the engine, took 24·2 lbs. of water per electrical horse-power per hour. That same engine running without superheat at the Edinburgh station took 31·3 lbs.; but when 65° of superheat was added, the consumption came down again to 24·5 lbs., or practically what it had been at Thames Ditton. This, he imagined, simply meant that the balance was the loss which would otherwise have occurred in the steam, comprising both the loss between the boiler and the engine, and also the great loss due to the increase of cylinder condensation caused by starting with wet initial steam. The superheating had thus saved all the loss in the steam-pipes, and had also brought the steam into the engine in a condition in which it did not so easily lend itself to heavy initial condensation.

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* See plan of Edinburgh station in connection with Mr. Burstall's paper, Proceedings 1895, Plate 150, Fig. 12.

(Professor Alex. B. W. Kennedy.)

In describing the aim of superheating (page 135), he should be disposed to include not only the counteracting of cylinder condensation, but also the saving of the large amount of loss which occurred undoubtedly by radiation from steam-pipes, flanges, and so on. In Edinburgh not only were the steam-pipes and boilers covered, but all the flanges were also carefully covered, which was no doubt partly the reason why so much superheat was obtained at so long a distance from the boilers. The actual fall of pressure in the steam-pipes from the boilers to the most distant engine, during a good many hours at full load, was from 4 lbs. to 5 lbs. only.

Historically he had one recollection which he should like to mention, in order to add to the author's memoranda on this subject. The firm with whom he was apprenticed, Messrs. J. and W. Dudgeon, of Millwall, had from 1860 to 1868 made a great many marine engines with superheaters. Their superheater consisted of an annular vessel placed on the top of the boiler, and forming really the base of the funnel. The steam was taken from the boiler into the top of this annular vessel, and made to circulate through passages up and down and around, and finally went away into the engines from the vessel on the opposite side to its entrance. The boiler pressure was about 25 lbs. per square inch above atmosphere; and in those days he was afraid the boiler steam must have been very wet, for over and over again large solid chunks of carbonate of lime used to be got out of the bottom of the superheaters, three or four inches thick and eight or nine inches long. They must have come, he presumed, with the water which was carried over by the steam in the first instance; and this he believed was what had led to the superheaters being given up.

Any method of increasing the output of boilers, such as that on which the author had specially commented (page 164), was a matter that affected all engineers closely. If they were going to get double or treble the duty that they could at present out of the same number of cubic feet of boiler house—and the author apparently thought he saw his way to getting it—they would really be doing quite as important a thing as if they were saving 10 or 15 per cent. in other directions.

Mr. Michael Longridge said there were two questions which would present themselves to everyone who had to design a superheater:—first, what degree of superheat should be aimed at; and second, how was it to be obtained. In the paper various degrees of superheat were mentioned; and the lowest of these, namely 45° (Table 2, page 141), was said to have effected a saving of 19 per cent. in coal. So large a saving he thought could not be credited to superheating. In Table 9 (page 157) savings of 17½ and 20 per cent. of steam were said to have resulted from superheating 118° and 102° respectively; but he doubted whether such large savings could be made by superheating practically dry steam by so little as 100°. It seemed to him that the great economies obtained were due in part to the fact that without the superheaters the boilers supplied water as well as steam to the engines; and this belief was strengthened by a remark* in the report from which the table was compiled, and by the fact that the boilers to which the superheaters were attached were elephant boilers—a type that often gave trouble by priming—and were connected to the engine by a pipe 125 feet long. Anyone expecting an economy of 20 per cent. from superheating steam from a Lancashire boiler he feared would be disappointed. A saving of 20 per cent. was a large amount; it meant suppressing a large proportion of the initial condensation in a well made cylinder. In some cases where he had made the calculation he had found that the heat supplied by a steam-jacket was sufficient to superheat the steam passing through the cylinder by 40° to 80° according to circumstances; but jackets were far from

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* "The water level in the boilers was kept very nearly constant by an automatic apparatus. The variation of level in the gauge glasses in individual boilers hardly exceeded 2 inches, and the mean level of all the boilers in use varied 1 inch, throughout the trials. The level in the gauge glasses was evidently affected somewhat by the variation of density of the mixture of steam and water in the boilers and by the oscillations due to steaming. Hence, I have come to the conclusion that it is more accurate to assume the quantity of water in the boilers constant throughout the trials, than to attempt any correction for variation of level." Report on Mr. Emile Schwoerer's system of superheating steam, by Professor W. Cawthorne Unwin, F.R.S., 4 May 1893.

(Mr. Michael Longridge.)
preventing initial condensation. Of course the amount of heat passing through a jacket would be more effective if supplied at a higher temperature to the inside of the cylinder; still he thought it would not prevent initial condensation. On the other hand the heat absorbed by the cylinder walls during admission was sufficient to superheat the steam by 400° to 500°. It would not be necessary to provide the whole of this heat, if it were supplied in superheated steam, because the cooling action of the walls would then be less energetic; but unless there were sufficient superheat to keep the steam dry not only during admission but throughout the stroke, that cooling action would always be considerable. He thought however that 400° of superheat was a limit which it would not be necessary to exceed. As an indication of what was required, he might refer to an experiment he had made with a non-condensing Corliss engine having an arrangement of valves on the inside of the covers, through which air at a temperature of about 500° Fahr. entered the cylinder during the exhaust stroke, wiping it out and drying the walls. A constant stream of hot air flowed through the jacket. With a boiler pressure of 116 lbs. and a cut-off at 16 per cent., the engine consumed 20·5 lbs. of steam and about 73 lbs. of air per indicated horse-power per hour. Both steam and air escaped at a temperature of about 212°; so that the heat lost by the air was sufficient to have superheated the steam to 500°, or, if the superheat in the air only were considered, to 280°. Yet there was at least 10 per cent. of water present at cut-off. But perhaps the best example to consider was Schmidt's engine and superheater, mentioned by Professor Unwin in his "James Forrest" lecture (Proceedings Inst. C. E., 1895, vol. cxxii, pages 177–8) as consuming 10·2 lbs. of steam per indicated horse-power per hour. Trials of this engine by Professor Schröter were reported in "Engineering" of 25 January and 22 March, 1895. The superheat at the cylinder was 230° in one test and 283° in another; at the boiler it was 288° and 300°. With 230° superheat the steam in the high-pressure cylinder was dry almost to the end of the stroke, and with 283° quite to the end. In the low-pressure cylinder however there was 16 per cent. of water, although the piston and part of the surface of the walls were jacketed with

steam at 280° superheat. This example he thought showed that, in order to obtain the highest economy, it was necessary to go in for a high degree of superheat. With an ordinary length of steam pipe he thought the best results would not be obtained with less than 300° or 350° superheat in the superheater; and even then the last example seemed to indicate, as would be expected, that in the case of a compound or triple engine the beneficial effect of the superheating would be confined to the first cylinder. This appeared to him to be the answer to the first question.

In considering the further question, how this degree of superheat was to be obtained, he would refer to the figures in Table 13 (pages 172–3). These were compiled partly from experiments he had himself made with the McPhail and Simpsons superheater, and partly from the experiments of others. Column 1 was derived from Table 1 in the paper; and column 10 from Table 2, on the supposition that the quantities of steam passing through the superheater and by-pass valves were proportional to the areas of the two, and that the superheat of 45° was the superheat after the mixture of the two currents, and not the superheat of the steam leaving the superheater. In column 10 he had had to estimate the temperature of the gases; the figures so estimated were enclosed in brackets. Column 2 was from an experiment with a Gehre superheater, communicated to him by Mr. Donkin; and here again the temperature of the gases was estimated. The next seven columns 3 to 9 were founded on Professor Schröter's trials of Schmidt's superheater. This superheater* consisted of two coils of pipe; the first coil, called the "preheater," was placed in the hottest gases, and received steam and water from the boiler, both the heating surfaces and the water surface of the boiler being so small as to encourage priming. After being dried in the preheater, the steam passed into a separator, and then into the second coil, or superheater proper, through which it travelled in a direction contrary to that of the gases. The figures in columns 5 and 8 pertained to the preheaters, and were calculated on the assumption that the steam entering the preheater contained

(*continued on page* 174.)

* "Engineering," 25 January 1895, page 112; and 22 March 1895, page 391.

(Mr. Michael Longridge.)

TABLE 13.—*Experiments with Superheaters.*

Name of Superheater.		Gehro. From Table 1, page 139.	Gehro. From Mr. Donkin.	Schmidt Preheater and Superheater. * Superheater.	* Superheater.	* Preheater.	* Superheater.	* Superheater.	* Preheater.	† Superheater.
		1	2	3	4	5	6	7	8	9
Surface in Heater	square feet	646	62·5	359	359	72	38·8	38·8	17·0	350
Weight of Steam per square foot per hour	lbs.	2·98	38·8	1·90	1·86	9·40	2·42	2·63	5·86	2·18
Final Temperature of Steam	Fahr.	388°	448°	687°	694°	422°	684°	702°	568°	674°
Initial " " "	Fahr.	348°	346°	422°	442°	354°	563°	568°	346°	374°
Degrees of Superheat	Fahr.	40°	102°	265°	252°	68°	121°	134°	222°	300°
Initial Temperature of Gases	Fahr.	600°		933°	877°	1260°	824°	834°	1253°	950°
Final " " "	Fahr.	510°		703°	692°	933°	744°	760°	853°	660°
Mean " " "	Fahr.	555°	[800°]	818°	785°	1097°	784°	797°	1053°	805°
Mean " " Steam	Fahr.	368°	397°	554°	568°	388°	623°	635°	457°	524°
Mean difference of temperature	Fahr.	187°	403°	264°	217°	709°	161°	162°	596°	281°
Heat transmitted per square foot per hour	Th. U.	57	1900	212	225	1931	140	169	1641	314
" " " " " " " per degree of difference of temperature	Th. U.	0·30	4·72	0·92	1·04	2·72	0·89	1·04	2·75	1·12

* "Engineering" 25 January 1895, page 114.

† "Engineering" 22 March 1895, page 391.

TABLE 13 (*continued*).—*Experiments with Superheaters.*

Name of Superheater.		Musgrave and Dixon's Superheater. From Table 2, page 141.	McPhail and Simpsons' Superheater. From Table 8, p. 156.	McPhail and Simpsons' Superheater. Mr. Longridge's experiments.					
		10	11	12	13	14	15	16	17
Surface in Heater	square feet	120	355	162	162	162	162	250	250
Weight of Steam per square foot per hour	lbs.	22·2	23·4	33·5	33·5	34·3	34·3	42·5	42·5
Final Temperature of Steam	Fahr.	420°	650°	473°	524°	425°	465°	520°	543°
Initial " "	Fahr.	340°	362°	299°	299°	299°	299°	320°	412°
Degrees of Superheat	Fahr.	80°	288°	174°	225°	126°	166°	200°	131°
Initial Temperature of Gases	Fahr.			1001°	1001°	977°	977°		
Final " "	Fahr.			669°	669°	641°	641°		
Mean " "	Fahr.	[820°]	1058°	835°	835°	809°	809°	1050°	1050°
Mean " Steam	Fahr.	380°	506°	386°	411°	362°	382°	420°	478°
Mean difference of temperature	Fahr.	440°	552°	449°	424°	447°	427°	630°	572°
Heat transmitted per square foot per hour	Th. U.	852	3235	2798	3617	2074	2733	4080	2672
" " " " " " " per degree of difference of temperature	Th. U.	1·94	5·86	6·23	8·53	4·64	6·40	6·48	4·67

(Mr. Michael Longridge.)
20 per cent. of water. Columns 3–4–6–7–9 referred to the superheaters proper. The lighter figures in these and the remaining columns were obtained by calculation from data furnished by the trials, and could be considered only as approximate. Column 11 was taken from Table 8. In the remaining columns 12 to 17, compiled from his own experiments, he could not say that the temperatures were absolutely correct, as he had no platinum thermometer when the experiments were made; but he had taken a good deal of trouble at the time to ascertain the errors, which were considerable, of the mercury-nitrogen thermometers used. If the figures in Table 13 were even approximately correct, they showed that, unless there were a considerable difference between the temperatures of the gases and of the steam, a large superheater would be required for obtaining the superheat desired; on the other hand, where there was a difference of 400° and upwards, a comparatively small surface would suffice. The exception to this conclusion was Musgrave and Dixon's superheater, whose performance was shown in column 10; here, although the difference of temperature was 440°, and the quantity of steam passing through the superheater was large in proportion to the superheating surface, the transmission of heat was only 1·94 units per square foot per hour per degree of difference in temperature. This apparent discrepancy he thought was explained by the drawing of the superheater in Plate 33; for it seemed to him that the gases would not pass through the superheater, but would go direct from the internal flues of the boiler to the bottom external flue. The author's experiment in column 11, and Mr. Donkin's in column 2, had given rates of transmission similar to his own experiments in columns 12 to 17. On the other hand, where the temperature of the gases was low, and the difference between this temperature and that of the steam was also low, as in column 1, no sufficient superheat was possible even with a large superheater. The answer to the second question therefore seemed to be that the superheater should not be placed in waste gases of low temperature, but in a hot place. In the latter position it need not be large. There must be a considerable head of temperature, something like 400°; which meant that, in order to get the steam

up to 600° or 650°, the temperature of the gases should be about 1,000°. With such conditions he thought a heat transmission might be counted on of about 5 units per square foot of surface per hour per degree of difference in temperature. No doubt others had arrived at substantially the same conclusions, but had hesitated about exposing a superheater to so high a temperature. As far as he could learn however, Messrs. McPhail and Simpsons, having the courage of their opinions, had shown that a superheater could be worked in such a temperature without rapid deterioration; and due credit he thought should be given to them for the knowledge their experience had provided. The high-temperature superheater he considered should be coupled to the main steam-pipe with a by-pass valve, as in Musgrave and Dixon's arrangement, and with a damper to shut off the gases when steam was not passing. There should also be some means of automatically preventing excessive temperature: such as a thermometer in the steam-pipe, with an electrical arrangement to close the valve of the superheater when the mercury rose to 600° or any other predetermined temperature. Such an arrangement he had seen in use for controlling the temperature of a greenhouse. With these precautions he thought steam might be superheated to 600° with great benefit.

Mr. John S. Raworth noticed that in the tests made with the Gehre and with the Musgrave and Dixon superheater, Tables 1 and 2, a high economy of coal was in both alike attributed to the use of the superheater. It must not be supposed however that the boiler had evaporated more water per pound of coal than it did without the superheater. If the superheater were placed in the position which no doubt was best for it, among the live gases of the boiler furnace, it was quite possible that it might detract from the efficiency of the boiler by taking away some of the heat which might otherwise have been used in evaporating water. But if it were placed in the waste gases, which Mr. Longridge had already pointed out (page 174) was a bad place, it could not by any possibility render the evaporative efficiency of the boiler either any better or any worse, except in so far as it might interfere with the draught. With both the Gehre and the

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Musgrave and Dixon superheater it seemed to him that the high efficiency attributed to the superheater was due simply to the boiler having happened accidentally on the occasion of using the superheater to evaporate a much larger quantity of water than it had done on the preceding occasion without the superheater. In Lancashire boilers experience showed that if the top coat of soot, which covered the sides of the boiler under ordinary circumstances to about half an inch in thickness, were either designedly or accidentally removed, the efficiency of the boiler would be improved forthwith about 15 per cent. The Lancashire boiler, as had been pointed out by Mr. Crompton (Journal of the Institution of Electrical Engineers, 26 April 1894, page 408), was ordinarily so deficient in heating surface, and its efficiency therefore so low, that it responded immediately to any touch which improved its heating capacity, either by the sides of the boiler being swept, or by some addition being made to its heating surface, as for instance by the addition of an economiser. In Table 9, on the other hand, it would be seen that in Professor Unwin's tests of the Schwoerer superheaters the evaporative power of the boilers had properly been eliminated, and attention was entirely confined to the question whether superheated steam was more economical to use in an engine than ordinary saturated steam. That point was brought out clearly, and the results were fairly consistent, the coal economy running fairly alongside of the steam economy: while the coal economy in the three tests was 17·6 and 18·5 and 20·1 per cent., the steam economy was respectively 20·9 and 13·6 and 20·9 per cent., showing that, when the experiments were carried out intelligently, the saving in coal was commensurate with the saving in steam. The McPhail apparatus was called a superheater, but it seemed to him to be only accidentally a superheater; for it would be noticed that in some of the best results recorded in the paper the steam was scarcely superheated at all, thereby seeming to show that the apparatus was not intended primarily to affect the consumption of steam in the engine, but simply to improve the boiler power. Most of the tables in the paper did not give the effect upon the engine at all, but simply the effect upon the boiler in the improvement of its evaporative

efficiency. According to the description and drawings of the apparatus, the steam from the boiler passed into the superheater, and having there collected heat from a live and active part of the furnace gases, re-transmitted this heat to the water in the boiler, came back again to the superheater, picked up more heat, gave this back again to the boiler, and then went on its way to the engine with but little superheat in it. Thus the total effect of the superheater, which showed it was not primarily a superheater, was simply to transfer heat from the live gases of the furnace to the water in the boiler. In a boiler which was originally working badly, the natural consequence of increasing its heating surface by 30 to 50 per cent. was a better evaporation; and he was glad to accept this result as following the natural law of heat transmission. The arrangement he thought had certainly one advantage, that, the superheating tubes being put in the position shown, and not having inside them water which was comparatively cold, the soot would not stick on them so readily as it would on water tubes. In every other respect, except the final residue of superheat, it seemed to him that the apparatus was simply an addition to the boiler, and not a superheater. In Table 6 it would be noticed that the water consumption of 39·7 lbs. per hour per electrical horse-power with the superheater was a better result than the 42·1 lbs. without the superheater; and he agreed with the explanation given in page 150 as to why the result was not quite so satisfactory as might have been expected. But he thought it was rather hard on a Willans engine to be associated, immediately after being overhauled, with so large a consumption of steam as 42·1 lbs. per hour per electrical horse-power. With regard to the increase in the capacity of the boiler and the improvement in the steaming, which were commented on in page 150, he understood that this test had been made by Professor Kennedy; and he was sure therefore that, in arriving at the boiler efficiency of 68·4 and 74·9 per cent. with cold feed, the requisite allowance had been made for the temperature of the feed-water.

At the outset of the paper it was stated that steam could not be superheated in the presence of the water from which it was evaporated, owing to the fact that the water took up the heat and evaporated

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into further saturated steam; and it was said to follow as a corollary that water could not exist in the presence of superheated steam. The latter fact might be perfectly true, and he had no doubt it was so; but he considered it must be an independent fact, and not a corollary from the other fact, because it did not follow that the conditions of forming a thing were the same as the conditions of its existence after it was formed. For instance, fine cotton yarn could not be formed in the presence of a dry atmosphere; but it did not follow that a dry atmosphere could not exist in the presence of cotton yarn. If therefore it was to be believed, as he had no doubt many engineers did believe, that water could not exist in the presence of superheated steam—at all events not much water—it must be clearly understood that this must be accepted as an independent fact which must be proved, but not as a corollary from the other statement.

Mr. Henry Davey, Member of Council, believed it was pretty generally accepted that superheating was conducive to economy; but notwithstanding all the experiments which had been made, the subject was still in a somewhat confused state, and no one, as far as he knew, had yet been able to say exactly what economy might be expected from any given conditions of superheating. Isherwood in America between 1860 and 1865 had tested the Wethered system of superheating in the engines of the ship "Adelaide," and had found that with about 60° of superheat there was about 15 per cent. economy in steam per indicated horse-power. So large an economy for so moderate an amount of superheat had led him to argue that close to the saturation point steam expanded irregularly. But there appeared to have been some doubt as to the measurement of the superheat, which was obtained from the waste heat of the furnace, and was not sufficient to prevent cylinder condensation entirely. It was obvious that, if the superheat was obtained from the waste heat of the furnace, it was then a boiler economy. It was at the same time also an engine economy; and he thought it was worth while to examine where the economy came in as regarded the engine, for it was important to know what might reasonably be expected from superheating. If reliance were placed on reports of the extraordinary

economy said to have been obtained, the question arose, why did not superheating rapidly become general? The truth he thought was that the economy was considerable, but that the practical application was difficult.

Apart from the question of utilizing the waste heat of the boiler, it would be seen from Fig. 30, Plate 40, how superheating affected the engine economy by increasing the area of the indicator diagram. It had often been alleged that adiabatic expansion would be the condition of maximum theoretical efficiency in a non-conducting cylinder; but a simple illustration was sufficient to show that practically it would not be so. A steam engine must have useless resistances, back pressure, clearances, and friction, all of which, together with cylinder condensation, constituted a dead charge amounting in practice to something like 30 to 40 per cent., or even more, out of the total power which would have been available under the conditions of working, if the useless resistances and cylinder condensation had not existed. The performance of work and adiabatic expansion in a non-conducting cylinder would be accompanied by the condensation represented by the disappearance of 2,500 units of heat per indicated horse-power per hour. Any addition of heat to the working steam, which would prevent this condensation in the cylinder, would increase the effective power in a larger degree than it would increase the total power. Thus in Fig. 30 let the ratio of the expenditure of heat to produce the area A be the same as that for the whole diagram; and let the area A be one-tenth of the whole diagram, or say one-seventh of the area B C D E; then by the expenditure of 10 per cent. more heat, the net or effective area might be increased by 15 per cent. To the actual engine cylinder however, in which conduction came into play, the same reasoning applied in a larger degree, because of the greater possibility of increasing the effective power by addition of heat to the working steam, in consequence of thereby arresting condensation. The hot-air engine had failed chiefly because the dead charges bore so large a proportion to the total output. In the steam engine, cylinder condensation was a big dead charge, which if wholly or partially neutralized would increase the percentage of net profit.

(Mr. Henry Davey.)
Thus in Fig. 31, Plate 40, let the area A represent the loss from cylinder condensation; and let it be assumed that by superheating or steam-jacketing this loss could be wholly or partially prevented. Then there would be two sources of net profit:—firstly, that already alluded to, namely increase of effective power; and secondly, the possibility of further increase of economy in adding the area B to the diagram by increased useful expansion; and the indicated power would be increased by the three areas A, B, C. There was a further possible element of economy in superheating, namely that of keeping the cylinder dry at the time of release, and thus minimizing the variation in temperature in the cylinder, from which arose the major portion of cylinder condensation. In this way it came to pass that the expenditure of one unit of heat in a steam-jacket effected a saving of more than one unit in the cylinder. If by superheating and steam-jacketing condensation in the cylinder could be entirely prevented, probably the steam engine would be in a condition of maximum practical efficiency for a given pressure and given ratio of expansion, because but little useful effect could be got simply from the increased pressure due to superheat.

There was a further economy to be obtained by getting the superheat from the waste heat of the boiler; but in doing so there must be no robbing Peter to pay Paul. A boiler might prime, or might be inefficient or too small; and a superheater attached to it might show a great economy. Some of the published results of superheating he had no doubt had been largely influenced from these causes. It must be remembered that, when superheated steam was used, the economy could not be truly stated by difference in weight of steam per indicated horse-power, unless the superheat was got for nothing. A saving of 20 per cent. in steam did not necessarily mean a saving of 20 per cent. in heat. When the superheat was obtained from the waste heat of the furnace, the economy in percentage both of steam and of coal should be the same; because the economy arose from increase of power, assuming the rate of evaporation to remain the same: except of course in the McPhail and Simpsons superheater, which was an evaporator and a superheater combined, and appeared to have a higher effect on the boiler than

on the engine. Considering that with modern pressures the initial steam was at about 350° Fahr., and that without superheating the water present at cut-off might be 30 per cent., it would be seen to what a high temperature the steam must be superheated in order to prevent initial condensation entirely.

Mr. Hugh McPhail said that, although the apparatus bearing his name had been spoken of as not a superheater (page 177), yet it had been made as a superheater, and it fulfilled he believed all the requirements of a superheater. The object in making the superheater in the form shown in the drawings was to get dry and superheated steam at a suitable temperature. Its use had been found by those who employed it to be attended with an economy of steam, which was not unforeseen, even if in amount it might seem to some to be accidental; and from his own experience he believed it had led to a new epoch in steam generation and economy. It suited not only as an evaporator, but also as a superheater; and it was probably sufficient to mention that there were a number of boilers at present working with high degrees of superheat, and one in particular with a superheat of 334°, which temperature was maintained uniform throughout the working of the boiler. The great object of this contrivance was to have a superheater which would be controlled by the pressure of the boiler with regular firing; and this object was now found to be fully attained in practical working. According as the boiler pressure was reduced or increased, the superheat was reduced or increased in proportion. The superheater was placed just in the proper position for taking up the greatest amount of heat from the hottest gases immediately on their leaving the furnace. It could not be got nearer to the furnace without diminishing the extent of the boiler heating-surface. At the times when cold air passed through the flue, there was a tendency for the superheater to become a condenser, as was the case with all superheaters so situated. Twelve superheaters, consisting only of superheating tubes in the flue without radiators inside the boiler, as shown in Plate 39, had been put in at Saltaire in 1866; and after they had worked for a short time the result was found

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to be that the engines had to be repaired. All the evils connected with superheating had cropped up there in the same way that they had cropped up in the time of Penn and the other pioneers of superheating. In his own apparatus, should the superheating tubes ever tend to become a condenser, the steam was kept dry by the temperature in the boiler; and in this way a fairly uniform temperature was maintained, sufficient to ensure perfectly dry steam. There were many points in regard to steam, about which ignorance was still prevalent; and one in particular was of much interest in connection with practical superheating: namely that, when once perfectly dry steam had been obtained by superheating, it was found that it never became saturated until its temperature had fallen a long way below the temperature corresponding with that of saturated steam at the boiler pressure. So long as the dry steam never came into contact with water, it did not become saturated till it had gone down much below the temperature of saturation. Superheated steam had been carried dry to a distance of 147 feet in a wrought-iron pipe of $2\frac{1}{2}$ inches diameter without any covering whatever, and had issued from the further end at the temperature and pressure of the boiler, working an engine at that distance better than it was worked with steam from a boiler alongside it at a higher pressure. At present great difficulty seemed to him to prevail in realising these and other practical results of superheating. In 1892 one of his superheaters had been put to work in connection with an old beam-engine in Legram's Lane, Bradford, which was receiving steam with 140° of superheat; and its use had been attended with an economy of 28 per cent. Since its application he had not heard of its having been repaired. In other instances superheaters were working with high temperatures, and gave no trouble whatever. This was simply because there was no variation of the steam in the superheater; it was not water at one time and steam at another, but was always steam at a high temperature, and therefore always dry steam. So high a degree of superheat as that mentioned by Mr. Longridge (page 174–5) he thought was not necessary. His own experience had been that the superheating need only be carried to such a degree above the temperature of saturation as to ensure the whole of the

steam being really dry. The dry steam then conveyed its heat to the engine piston, and the heat was there transformed into work, as it ought to be; and at the end of the stroke there was but little water remaining in the steam, because there was less equivalent weight, volume for volume, than in saturated steam to begin with. What was wanted was really dry steam, whatever its temperature; and with dry steam there was found to be economy in many ways. In condensing engines less condensing water was wanted, because there was less weight of exhaust to deal with. As to any sediment forming in the superheating tubes from priming water coming over in the steam, he believed it was impossible that there should ever be any water coming over in this apparatus; and having examined the superheating tubes over and over again, he had found there was no sediment whatever in them.

Mr. J. F. L. Crosland considered the greatest credit was due to the author for this paper bringing forward the results of his experiments at Charing Cross. It was a matter of great importance to show how the boiler power could be increased nearly two and a half times. The Babcock and Wilcox boiler which the author was using had previously been evaporating only 3,457 lbs. of water per hour; and by means of a superheater, evaporator, and induced draught, the evaporation had now been increased to 8,294 lbs. (page 155). It seemed to him that this was a matter which interested every user of steam power; and they were much indebted to the author for bringing it forward. He had himself had about four years' experience of superheating in the years 1859 to 1863 with an apparatus of his father's, consisting of pipes arranged in boiler flues in a manner similar to the Gehre superheater shown in Fig. 3, Plate 31. The pipes were not fixed in a cylindrical shell as there shown, but were arranged in a serpentine form in the upper flues of the boiler, as shown in Fig. 29, Plate 40. When using this apparatus great difficulty was experienced in lubricating the engine. Animal and vegetable oils—the only ones which could then be procured—dried up, and the steam burned the stuffing in the stuffing-boxes. Another difficulty was to keep the steam-pipes

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properly covered. A great deal of animal and vegetable fibre was used at that time for covering boilers and steam-pipes, secured by wood lagging; and at the increased temperature the material rapidly charred away, and in some cases actually took fire. One of the objections also to the use of superheated steam was its great readiness to give up its heat. In some experiments which he had recently been making with a superheater, the steam was raised in the superheater from its ordinary temperature of 320° to 443°; but in passing to the engine it lost a considerable amount of that superheat, falling to 376°. A careful test for dryness showed that the saturated steam was remarkably free from water, containing not more than 0·4 per cent. before superheating. The effect of the secured superheat of 56° in the engine cylinder was to reduce the weight of steam used in the engine from 22·82 lbs. per indicated horse-power per hour to about 20·59 lbs., which meant a saving of about 10 per cent. But that advantage was entirely lost in the coal account, owing to extra radiation from the steam-pipes, which were not carefully and properly covered in some parts. The much greater loss that would occur through radiation from steam-pipes when containing superheated steam than when containing saturated steam was perhaps not quite fully realised. That extra loss with the superheated steam was just sufficient to balance the advantage obtained from the superheat in the quantity of steam used in his experiments. These showed that with a superheat of about 56° in the cylinder it was possible to obtain an economy of about 10 per cent., provided care was taken to prevent loss by radiation. In using superheated steam great care must be taken to cover with a good non-conducting material not only steam-pipes and their flanges, but also the cylinder, valve-boxes, and every part of the engine from which heat could escape. The McPhail superheater he had himself found highly effective, both as a superheater and also as an evaporator; and it would be seen on consideration that—as the superheated steam was carried into and through the boiler below the water-line, and then brought out and passed again through superheating pipes, and a second time carried through the water in the boiler before being finally delivered by the main steam-pipe to the engine—it was

easy to regulate the amount of superheat by proportioning the surface of the radiating pipes inside the boiler to that of the superheating pipes outside. In that way the superheat could be regulated to any amount, up to the full superheat given by the U shaped pipes in the combustion chamber.

The President here adjourned the discussion to the following meeting; and before separating he was sure the members would give Mr. Patchell a preliminary vote of thanks for his valuable paper.

Discussion, 29 *April* 1896.

Mr. Patchell said that, with respect to the extra evaporation of the Babcock and Wilcox boilers at Maiden Lane, it seemed to be thought that he had been putting forward the duty of those boilers as something remarkable; whereas from Table 6, line 8 (page 151), it was seen that the water evaporated per hour per square foot of heating surface was 3,457 lbs. ÷ 1,827 sq. ft. = about 1·9 lb. With the induced draught the boilers were now evaporating about 4·8 lbs., which seemed to be about an average evaporation, and might be accepted as good work. It was about the mean of a long series of twenty or twenty-five experiments published by Professor Kennedy and Mr. Bryan Donkin, excluding a special test of a Merryweather fire-engine, which ran up to 13 lbs. These water-tube boilers had so much heating surface which under normal conditions was purely nominal, that they could not rank high in evaporation per square foot of heating surface. The problem he had had to solve had been to get more steam out of a limited boiler room, with boilers which were already doing their best; and to get it without interrupting the working of the electric lighting machinery. The means employed for doing so, which were detailed fully in the paper, had resulted in raising the power of the two boilers practically three times, and in getting superheated in place of wet steam; and this

(Mr. Patchell.)
had been accomplished at considerably less than what would have been the cost of one new boiler. The boilers were working quite easily, with only such a draught as was obtained in many factory chimneys, namely from $\frac{3}{4}$ inch to 1 inch of water gauge. By forcing the fan and engine, the boilers could be made to do a great deal more; but he did not wish to force them, though he should have every confidence in doing so, if necessary. The installation at Maiden Lane was not an experimental one; it had to fulfil the rather momentous duty of continuously supplying electric current at steady pressure for electric lighting: which work had to be done with the greatest regularity.

The scaling up of the superheater tubes was a point about which some doubt had at first been felt, but on which he had now no misgivings at all. Since the first superheater was put in, it had worked 12,600 hours; the second had worked 9,600 hours; in neither had there been the slightest trouble with the tubes, and there was not even a sign of scaling.

In the paper itself he had purposely refrained from giving any opinions of his own, because, when he had been asked to prepare the paper, he had understood that facts and not opinions were what was wanted; and he hoped a few more facts might be elicited in the remainder of the present discussion.

Professor W. Cawthorne Unwin was of opinion that what was now wanted was theory and not facts, in relation to the subject of steam superheating. Thirty or forty years ago a mass of facts had been collected about the use of superheated steam; and there was not one of the large tests made at that time which did not show a large economy from the use of superheated steam. Anyone wanting more facts would find in the Bulletin of the Alsatian Society of Steam Users a mass of facts showing that in every case the use of superheated steam had effected a considerable economy. The reason why superheated steam was not more used now was not because there were no facts, but because engineers had not quite sufficiently realised the reason of the advantage which superheating gave. In any scientific classification three ways of using steam in an engine

must be recognised. There was the ordinary use of dry or nearly dry steam, in which case the steam in the engine cylinder was always wet steam. Then there was the use of steam moderately superheated, that is, to about 100° or 120° Fahr. above the temperature of saturation; and in that case also the steam in the cylinder became wet steam. Lastly there was the use of highly superheated steam, in which case the steam would be dry when working in the cylinder. As far as he knew, there was only one instance in which highly superheated steam had been used on a practical scale, namely by Herr Schmidt in Germany; and it was too soon yet to say whether the use of steam in that way would prove to be practically successful. It was successful economically in experiment; but whether it would prove that highly superheated steam could be practically used successfully had yet to be seen. As there was no reference in the paper to the use of highly superheated steam, he would confine his remarks to moderately superheated steam, namely steam heated to 100° or 120° Fahr. above the temperature of saturation: in which case the steam when used in the engine was always wet at cut-off. In using moderately superheated steam, the heat contained in the steam as superheat was entirely spent in heating the cylinder, and thereby reducing the cylinder condensation. It took the place of jacket heat, acting in the same way, and for the same purpose; and the range of temperature in the cylinder was not increased. Therefore he thought that, in a recent paper* by Capt. Sankey on the thermal efficiency of steam engines, it had been wrong to adopt for engines using superheated steam a different standard from that for ordinary engines using saturated steam, unless the adoption of the different standard were explicitly limited to engines in which the steam retained its superheat up to the point of cut-off.

The gain in economy directly due to the use of superheated steam was an engine gain, and not a boiler gain. The gain must be measured in terms of the steam used per indicated horse-power hour; or, to be more accurate, in thermal units per horse-power minute. It was exactly of the same kind, and due to the same

* Proceedings Inst. C.E., 1896, vol. cxxv, page 182.

(Professor W. Cawthorne Unwin.)

causes, as the gain in using a steam-jacket. If a boiler was working under the best conditions, if the air supply and the proportions of the boiler were the best, then there could be no gain in boiler efficiency due to the addition of a superheater, at least as far as he knew. On the other hand practical engineers had to recognise that in many boilers the best conditions were not realised; therefore it came about that, in most instances where superheaters were used, they were in connection with boilers where some of the heat which might in a perfect boiler be utilised was wasted; and then it generally happened that there was a boiler gain, as well as an engine gain. To a great extent the amount of boiler gain that was realised additional to engine gain was a measure of the badness of the boiler to which the superheater was applied. In the paper * he had already referred to, on the thermal efficiency of steam engines, it had been rightly pointed out that, in a trial in which 10·2 lbs. of highly superheated steam had been used per horse-power hour, this consumption would be equivalent, in the amount of heat absorbed in the boiler, to 11·46 lbs. of saturated steam. But when it was added that the heat expenditure "of course" meant coal consumption, he objected to these words as begging the question, because he considered it was not a matter of course that the coal consumption would be increased proportionately to the total heat of the steam; it was a matter of experiment. In a large number of experiments made in Alsace, where great attention was paid to the use of coal in good boilers and the boilers were well worked, it had been found that the addition of a superheater involved a boiler gain, and that the coal economy due to superheating was at least equal to the steam economy.

In turning back to an ancient experiment in 1828, when fires had been built round the cylinders and steam-pipes (page 135), the author had treated it as an instance of the use of superheated steam.

* Proceedings Inst. C. E., 1896, vol. cxxv, page 207:—"If it is found that an engine using superheated steam at 650° Fahr. requires 10·2 lbs. of feed-water per I.H.P., this, so far as heat expenditure is concerned, which of course means coal-consumption, is equivalent to 11·46 lbs. of feed-water when compared with an engine using saturated steam at 100 lbs. pressure."

In those early days, when engines worked at from five to seven strokes per minute, it had been found that heating the outside of the cylinder with a steam-jacket produced a large economy; and some engineers went further and put a fire round the cylinder. It was possible, though he did not know whether it was so, that the steam had thereby been superheated; but he believed they had not known in the least what they were about. They had no followers, and they established no practice; and he did not attach any importance to those early experiments. In page 136 it was said that Trevithick had been combating cylinder condensation for a long period; but he doubted whether Trevithick knew what cylinder condensation was. At any rate it was rather striking that in the history of superheating in the paper there was no reference to the fact that Hirn was the one man who had discovered the real cause of the efficiency of superheating. It was not in 1850 as mentioned in page 136, but in 1855, that superheating was really first intelligently used; and it was not until 1859 that it came to be used in this country.* It was Hirn who established superheating; and superheating had been used since 1855 to the present day continuously in Alsace. While the author had been endeavouring here and there to find experiments in this country, there was hardly a well-worked mill in Alsace at the present time which was not using superheated steam.

The particular defect of the present paper seemed to him to lie in the fact that boiler economy and engine economy were completely mixed up; in a large number of examples of superheating, no data at all of superheating economy appeared to have been given. The author gave only the data of boiler economy; and even in this connection he had not given data to determine whether—in two trials of the same boiler, one with superheated steam and the other with saturated steam—the conditions were so nearly alike that the

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* Professor Dwelshauvers-Dery has pointed out that Ferdinand Spineux made an experiment in the use of superheated steam in 1840, and found an economy. Spineux competed for a prize for the greatest improvement in steam engines. "Engineering," 14 Feb. 1890, page 174.

(Professor W. Cawthorne Unwin.)
economy could in any kind of way be attributed to superheating. In any boiler the largest waste was that of the chimney: it might rise to 50 per cent. of the heat generated in the furnace, and it might fall to 20 per cent. or even less; yet in no one instance, where there was apparently a large economy in the working of the boiler, had the data been furnished of chimney waste. From the data given in some instances indeed the probability could even be perceived that the chimney waste had not been the same with the superheated steam as without. It seemed to him somewhat of a mistake in the paper to include the McPhail and Simpsons so-called superheater amongst the others, instead of classifying it by itself. The steam was here taken out of the boiler and heated, and then back again into the boiler and cooled: recalling the story of the king of France, who was said to have marched his men up the hill and then down again. In the previous discussion he believed some hint had been thrown out that steam which had been superheated and then reduced in temperature was of a different physical nature to ordinary steam (page 182); that was incredible. The fact appeared to him to be that the McPhail superheater, if it was a superheater, was so by accident and not by design. The only one of the experiments with this superheater which was at all completely given in the paper was that made by Professor Kennedy (page 151), from which it appeared that when the steam reached the engine there was about 7° of superheat, with which there was some small engine economy, because the steam was drier than when the superheater was not used. It was hardly fair however to put alongside other superheaters, which would give 100° or 120° of superheat, a superheater which gave only 7°. That experiment was in a certain way characteristic. More details were given of it in Table 6 (page 151) than of any of the other experiments. It appeared that without the superheater the evaporation from and at 212° was 10·50 lbs. of water per lb. of coal, and that when the superheater was added it went up to 11·47 lbs. That was a large boiler gain of 10 per cent., not an engine gain; and he wished to know whether the boiler had been worked in the same way in both experiments, that is, whether the advantage was really due to superheating, or to the difference in the

mode of working the boiler, or merely to additional heating surface. The chimney waste was not given in the experiment; but there was a significant fact given: the temperature of the gases leaving the boiler was 67° higher when the superheater was used and when the economy was greatest, than it was when the superheater was out of use and the economy was least. Thence it could be directly inferred that the air supply per pound of fuel was different in the two cases; and therefore it might be inferred pretty surely that the boiler was not worked in the two cases with the same air supply per pound of fuel, or in the same way. There were two or three other trials mentioned of the McPhail superheater, in which the engine economy, the only characteristic economy of superheating, was not given at all, but in which there appeared to be a considerable boiler gain, especially a large gain in evaporation. In the trials, while the heating surface of the boiler was carefully given, the amount of superheater surface was not given. In Table 4 (page 146), for instance, the evaporation went up from 7·41 lbs. per hour per square foot of heating surface when the superheater was out of use, to 9·96 lbs. when it was in use. As far as he could make the figures out, the apparent gain in evaporation simply meant that the evaporation had been calculated on the boiler surface alone without including the superheating surface. If a large superheating surface were added to a boiler, it would absorb more heat and evaporate more water; and if the evaporation had really been calculated on the heating surface of the boiler alone, without including the surface of the superheater, it was an extraordinary mode of calculation. The Thornliebank tests in Table 5 (pages 148–9) were almost the same, only rather worse. In the McPhail superheater he suspected that the radiator or de-superheater would be gradually abandoned: in which case the apparatus would become merely the old superheater constructed forty years ago by Hirn and still existing in Colmar. The only characteristic feature of the McPhail superheater was the use of the de-superheating or radiating tubes in the boiler. As to whether there was any possible advantage in these internal tubes, it was said that they were necessary because they moderated the fluctuations in the temperature of the superheated steam; and it was possible there were instances

(Professor W. Cawthorne Unwin.)

where this result occurred. But before accepting the statement, he should like the fact to be ascertained. It would be easy to measure during a day of varying load the temperature of the superheated steam from a superheater worked with the internal radiating tubes, and to see whether the fluctuations were or were not moderated by the radiating tubes. At present he believed there were no facts to prove that the moderating effect on the fluctuations of the temperature really occurred. But supposing it were admitted, the further question had to be asked, whether any moderating of the fluctuations in the temperature of superheated steam was required. An admirable 500-H.P. compound engine which he had tested in Alsace had been working there perfectly for two years with steam superheated in an ordinary superheater without regulation: the cylinder covers had never been off, and the engine was using only two kilogrammes or $4\frac{1}{2}$ lbs. of oil per day. Having seen so many superheaters working, he was sceptical as to the necessity for any regulation of the temperature of the superheated steam, provided only the superheaters were properly placed. This was a point of some importance. In the early years, from 1860 to 1870, superheaters had almost invariably been placed in the uptake of the furnace; they had been used chiefly in marine engines and fixed in the uptake, which was just the place where the temperature of the gases was lowest, and therefore the efficiency of the superheating surface least. It was also just the place where the fluctuations in the temperature of the gases were greatest. It was therefore the wrong place for a superheater, though the right place for a fuel economiser. If a proper superheater were wanted, it must be placed near the furnace, where the fluctuations in the temperature followed the demand for steam, and where the efficiency of the superheating surface would be so much greater that a smaller superheater would suffice. The whole secret of using superheated steam successfully, he believed, lay in rightly placing the superheater, and in rightly proportioning its surface, both of which were matters purely of experience.

These criticisms he had offered, because it was only by discussion that the points of the subject could be brought out. Having looked

a good deal into experiments on superheated steam, he was convinced that, in most of the ordinary engines now used, a net steam economy could be obtained of from 15 to 20 per cent. by superheating; and that with a superheater added to the boiler there would be at least as great an economy of coal. This he thought was a gain large and important enough to lead to the use of superheaters even in a country where coal was as cheap as it was here. In Alsace he could find no trace of decay in the superheaters placed near the furnaces, no trace that they were injured internally by deposit, and no trace that the cylinders of the engines using superheated steam were injured when proper oil was used for lubrication. The safety of the superheater was a question of some importance; and he believed that ultimately the particular form of superheater to be adopted would turn mainly on the question of which form of superheater was capable of standing a tolerably high temperature continuously, without requiring any attention and without sustaining any injury. In Alsace, where a low class of stokers were employed who paid no attention to the temperature of the superheater, he had found that in some of the mills to which he went the men did not even know whether the superheater was in action or not.

Mr. John Phillips mentioned that in 1851 he had been engineer on board the "Avon," a vessel belonging to the Royal Mail Steam Packet Co., which was fitted with combined-steam superheating apparatus, he believed on Wethered's system, but it was not allowed to be used. Superheating apparatus on that system had also been fitted in vessels in the navy called the "Dee" and the "Black Eagle"; Mr. Charles Atherton, chief engineer of Woolwich Dockyard, had made some experiments with those vessels in February and July 1856, which were published by Mr. Robert Murray in a rudimentary treatise on the marine engine. Having himself been accustomed to superheaters from that time until they were given up about 1878, he had always found that the gain ranged somewhere about 20 per cent. Most of the superheaters were placed in the bottom of the funnel. The insides of the tubes, instead of decaying, were found to be covered with a deposit of black rust,

(Mr. John Phillips.)
which he believed had since been applied to the Barff process. The credit of the invention or application of combined-steam superheating he thought should be given to Wethered, who was an American. Rankine had rightly mentioned Wethered as the inventor of this system; and in Fairbairn's treatise on millwork the first introduction of superheating was ascribed to Frost, also an American. The question really seemed to be whether the gain by the use of a comparatively light weight of superheater was not greater than was obtained by increasing the size of the boiler. Within his own recollection superheating had been used on a large scale for marine engines, and he had not heard that any difficulty had been found with it when properly fitted and used. It had been abandoned only when higher pressures of steam came to be introduced in later years.

Professor Unwin said he had known Mr. Wethered himself, and he was sure that the date 1851 was too early for the introduction of his plan of combined steam in this country.

Mr. Druitt Halpin pointed out that Mr. Wethered himself, in his own paper in 1860, to which reference had been made by Mr. Patchell in page 137, had distinctly stated that he had introduced his plan of combined steam into this country four years previously: which would bring the date of its introduction to 1856. That was a year later than the date mentioned by Professor Unwin (page 189) in connection with the name of Hirn.

Mr. Bryan Donkin, Member of Council, agreed with Professor Unwin that the Alsatian engineers had been foremost in the use of superheated steam; he had himself visited many of the mills there. From the time of Hirn they had gradually extended its application; and he imagined that it was now employed for about 15,000 to 20,000 horse-power. The control or regulation of the temperature of superheated steam he thought was not of great importance, the result being only to cause the superheat to last a little longer or shorter time in the cylinder, which seemed to make but little difference in the economy of working an engine. In

England engineers seemed at last to realise the great importance of superheating steam; and the question arose, why was superheated steam more economical than saturated? It would naturally be answered that there was so much less cylinder condensation per square foot of internal surface; but this did not really answer the question, why was there less cylinder condensation? Many experiments had shown that with saturated steam, the hotter the cylinder walls, the less was the condensation: in other words, if the temperature of the walls was raised by efficient jackets or by other means, so as to reduce the difference of temperature between the steam and the walls, the result was economy and diminished condensation. In some experiments he had made with superheated steam, he had found that the temperature of the walls was considerably raised, in comparison with what it was when saturated steam was used. The extra heat in the steam seemed to go to raise the temperature of the iron walls, thereby producing a considerable gain. The superheated steam soon became saturated in the cylinder, sometimes even before the piston moved; but it had already done good by heating the walls, and the result was always economy. The mere jacketing of cylinders with superheated steam was beneficial in most cases, even without the circulation of superheated steam through the jackets; the percentage of steam present in the cylinder at exhaust was higher, or in other words the rate of condensation was less. The paper he considered had not given sufficient details in Tables 3 to 5 respecting the heating surface of the superheating pipes apart from that of the boiler; and it was difficult to make out whether the heating surface which was referred to was that of the boiler or of the superheater or of both. An interesting way of representing the effect of superheated steam was by means of the entropy diagram. Several entropy diagrams had been published lately, which showed plainly the action of the steam in the cylinder. At present a fair start had been made with superheated steam in stationary engines; but in locomotives no recent experiments had been made that he knew of, although the temperature of their exhaust gases was fairly high. Marine engineers also seemed to remember too well the

(Mr. Bryan Donkin.)
many failures of superheated steam thirty years ago, with the inferior materials, inadequate heating surfaces, and bad lubricants then in use. Some enterprising engineer he hoped would take the matter up; for at sea it was of much greater importance than on land to get the greatest economy, and the weight of the superheating pipes was but small. Some experiments in the direction of economy in both locomotives and marine engines seemed to be highly desirable. The superheating pipes seemed to him to involve the question of transmission of heat. The superheater consisted of a considerable surface exposed to the hot gases, heating the cooler steam; and Mr. Longridge's Table 13 (pages 172–3) was interesting and instructive as to the transmission of heat per square foot of heating surface in the various examples. The degree of superheat varied with the weight of steam passing per square foot per hour through the superheating pipes, and especially with the cleanliness of the pipes, the temperature of the gases, and many other conditions. In the author's interesting boiler experiments the results given pertained only to the generation of the superheated steam; as far as he could see, superheated steam had not yet been used at all by him in the engines; but he hoped he would succeed in thus utilizing it. In an interesting German superheater by Schmidt the superheating was done in stages; he had seen the apparatus at work, and had made some experiments with it. An important experiment had lately been made by Professor Schröter on an economical 1,500-H.P. triple-expansion horizontal engine working with the low steam-pressure of only 85 lbs. per square inch. There were four cylinders—a high, an intermediate, and two low-pressure. Their diameters were respectively $27\frac{1}{2}$ and $43\frac{1}{4}$ and $45\frac{1}{4}$ inches, stroke $5\frac{1}{4}$ feet, giving 630 feet piston-speed at 60 revolutions per minute; two cranks, one on each side, with a rope-driving fly-wheel in the middle. All the four cylinders could be steam-jacketed. The temperature of superheat was nearly always about 100° Fahr. Experiments were made with the superheated steam both inside the cylinders and in the jackets. The mechanical efficiency of the engine was 83 to 85 per cent. The most economical result obtained, when using superheated steam of 100° Fahr. with the low boiler-pressure of 85 lbs. and indicating

1,000 H.P., was 11·9 lbs. per indicated H.P. hour. There was much less cylinder condensation and much less water present in the steam when superheated steam was used. The thermal efficiency of the engine was about 16 per cent. with superheated steam. With 1,200 brake H.P. superheating gave 11 per cent. advantage as compared with saturated steam; and with 1,000 brake H.P. the saving was reckoned at 10½ per cent. In some trials published by the Boiler Association in Germany, with steam pressure 112 lbs. per square inch and power 256 H.P., the degree of superheat was 150° Fahr. at the engine, after allowing for loss in the steam pipe. The engine was a compound Corliss, and used 15·3 lbs. per I.H.P. of saturated steam, and 13·7 lbs. of superheated steam, showing a gain of 1·6 lb. per I.H.P. by using superheated steam, or 10 per cent., which agreed with other results. The Boiler Association reported that they generally found no difficulty with superheated steam, when mineral oil was used. In a paper read before that association in 1895 Mr. Walther Meunier had reported that a large number of engines had been working with superheated steam for some years in Alsace; and he considered that the loss of temperature in the steam pipes per yard run, even when they were well covered, was 2° Fahr., assuming 500° F. to be the temperature of the steam, and the pipes to be all indoors.

The interesting electrical thermometer designed by Mr. Frederic W. Burstall he hoped would soon be produced as a commercial instrument. If it could be made at a moderate cost, he had no doubt it would be largely used for a number of practical purposes.

Mr. Frederic W. Burstall exhibited specimens of the platinum thermometers shown in Figs. 33 and 34, Plate 42. These thermometers had been designed by his brother, Mr. Henry R. J. Burstall, and himself, for Professor Kennedy, for determining the amount of superheating in the superheaters and steam pipes at the Edinburgh electric lighting station. When the superheaters were first put in there, attempts had been made to measure the temperature of the steam by mercury thermometers placed in mercury cups

(Mr. Frederic W. Burstall.)

dipping into the steam; but the temperatures so shown were so obviously wrong that some other means of measurement had to be tried. The mercury thermometers themselves had been found correct, when tested against a standard; but variations and errors of from 20° to 50° Fahr. were shown when in position. On testing the thermometers all together in a well-stirred bath, it was found that when the temperature was rising or falling, even at a slow rate, differences of as much as 15° were shown between two thermometers of the same dimensions and make, notwithstanding that the two instruments agreed when in a bath at a steady temperature. In the mercury cups a movement of only one inch of the thermometer made a difference in its reading of 40°. The special point of the platinum thermometer exhibited was that the whole of the bulb, which was a fine platinum wire, was in actual contact with the steam; and therefore the thermometer must indicate the actual temperature of the steam, and would follow any changes in it, however rapid. As shown in Plate 42, it consisted of a coil of fine platinum wire W, wound on thin strips of mica MM; these were attached by screws to two leads LL, which passed through a brass plug P, and were insulated from it. The resistance of the coil was determined by suitable means, and the temperature read off on a curve, which was drawn out from the known constants of the coil. One great advantage of all forms of the resistance thermometer was that the reading could be taken from any convenient point, and at any reasonable distance from the thermometer. For ordinary practical work the platinum thermometer had a great advantage over most forms in the fact that its constants never varied, and it was constructed of materials which were not brittle like glass. One of the thermometers exhibited had been in a superheater at Edinburgh for certainly a week, and he believed for nearly a month; it had then been sent to London by post, and on arrival it had been checked over, and found not to have varied its constants. The pressure in the superheater was 160 lbs. per square inch, and the superheat varied from 50° to 80° Fahr. The instrument mentioned by the author was the first bare platinum-wire thermometer which had been made, and had been in the superheater at Maiden Lane for some days continuously in a temperature of over

320° C. or 610° F. It was found necessary to protect the wire from particles of solid matter and from water in the steam by means of a wire-gauze screen; but in a steam-pipe where the steam was dry it had been found that the wire was amply strong enough to stand the rush of steam, even at a high velocity.

Mr. Edward Perrett said that more than twenty years ago, on behalf of Mr. M. P. W. Boulton, who was the son of Matthew Boulton the partner of James Watt, he had commenced a number of experiments on superheating, which had been carried on for twelve years, and eventually led to the trial of the engine sketched in Plate 41. It was a vertical two-cylinder engine with cranks at right angles, and had previously been used for compressed-air experiments. The first cylinder A was 10½ inches diameter and 9 inches stroke, having a trunk 7½ inches diameter at the upper end. The second C was an ordinary cylinder 12 inches diameter and 12 inches stroke, immersed in a steam reservoir R. The superheater S was similar in construction to a Cowper fire-brick hot-blast stove, and had a safety-valve at V on the top. Steam was supplied by a small 8 H.P. vertical boiler B, working at 120 lbs. pressure per square inch. The steam was taken direct from the boiler into the annular space in the top of the first cylinder, from which it was exhausted into the superheater, entering the latter at about 60 lbs. pressure; no heat was lost during expansion, in consequence of the bottom half of the cylinder having been heated by the superheated steam in the preceding upstroke. From the superheater it went into the bottom of the first cylinder, whence it was exhausted into the reservoir R, from which it worked the double-acting low-pressure cylinder C in the ordinary way. Many difficulties were experienced in constructing it, because the temperature of the steam was about 580° Fahr. on entering the bottom of the first cylinder, and the pipe from the superheater to the engine became dull red-hot.

The President said the temperature must be much higher than 580° Fahr. to make the steam-pipe red-hot.

Mr. Perrett had no doubt the steam was hotter than 580° on leaving the superheater, and that it got rapidly cooler, the thermometer showing 580° where the steam entered the bottom of the first cylinder. The result of six months' experimental working of the engine was a consumption of 9 lbs. of water in the boiler and 0·2 lb. of coal in the heater per horse-power per hour; the power was measured by a brake on the fly-wheel. The late Mr. D. K. Clark, who had experimented on the engine, had reported that, if a new engine were made of larger size, it might be expected to require only 0·8 lb. of coal per horse-power per hour. Owing however to the death of Mr. Boulton, nothing further had been done with the engine to the present time.

Mr. Jeremiah Head, Past-President, said that ten years ago, when the Boulton superheating engine was new, he had made, on behalf of a firm of manufacturers, a series of experiments upon it in conjunction with Mr. Perrett, of which he had preserved the results. As a somewhat remarkable instance of superheating in an unusual way, he thought it was desirable that it should be permanently recorded. The chief novelty in the arrangement was the employment, for the purpose of superheating the steam, of the Siemens method of regeneration, which was so successfully applied to blast-furnace stoves and open-hearth furnaces; he did not himself know of any other instance in which superheating had been effected by bringing the steam into direct contact with the surfaces of red-hot brickwork. In the experiments he had made, the vertical boiler B, Plate 41, raised steam to say 105 lbs. absolute per square inch. The superheater S was a cast-iron bell-shaped vessel with a fire-grate and furnace at the bottom, the door of which could be hermetically sealed; and a pile of chequer brickwork was built up in the inside. On the opposite side to the furnace door was a long tube, which was led away horizontally and formed a chimney at the further end; at the near end was a valve by which it could be closed. In preparing to work the engine, and before the steam was got up, a fire was lit on the grate of the superheater, the chimney valve was opened, the flames passed up through the chequer

brickwork, down round the outside of the mass, and so away to the chimney. That went on until the whole of the brickwork was red or white hot. Then the fire was drawn, the chimney valve and fire-door were closed, and the boiler-pressure being up, steam was admitted direct into the annular space in the top of the first cylinder A, which had a trunk on the top of the piston. On the lower side the piston was of full area, but was protected by a block from the excessive heat of the superheated steam. In the downstroke of the piston the steam was cut off at half stroke. When the piston ascended again, the steam from the annulus was exhausted through the pipe E into the bottom of the heater. Taking the mean of ten runs of 3,000 revolutions each, which had been made at the speed of about 125 revolutions per minute during the experiments he had conducted, the boiler steam of 105 lbs. absolute pressure, after having been cut off at half stroke and exhausted, had fallen to 46 lbs. absolute, and the temperature to 275° Fahr., which was the temperature of saturated steam at that pressure. The saturated steam, entering the superheater close to the chimney valve, went through the mass of hot brickwork, took up its superheat, and passed out through the siphon pipe D to the valve F, which was simply a piston valve worked by an eccentric. By the heater the temperature of the steam was raised from 275° to 440°, or something like 165° of superheat. It then passed into the bottom of the first cylinder A, which was called the hot cylinder, and pushed the piston up, being cut off at half stroke. When the stroke was completed, the valve G, which was also a piston valve worked by an eccentric, was opened. By this time the temperature of the steam had fallen from 440° to 325°, and the pressure to about 28 lbs. absolute, so that there was still nearly 80° of superheat in the steam when exhausting through the valve G into the reservoir R, which surrounded the second cylinder C. Here the pressure was 24 lbs. absolute, and the temperature 238°. As this was the proper temperature for saturated steam at that pressure, it was seen that the whole of the original superheat of about 165° had by this time disappeared, and the steam had

(*continued on page* 206)

(Mr. Jeremiah Head.)

TABLE 14.—*Trials of Experimental Superheated-Steam Engine.* 24 March 1886. *See Plate* 41.

Saturated Steam in High-pressure annulus, 7½ and 10½ inches diameter, 9 inches stroke, cut-off at half-stroke.
Superheated Steam in Intermediate cylinder (hot-cylinder bottom), 10½ inches diameter, 9 inches stroke, cut-off at half-stroke.
Low-pressure cylinder, 12 inches diameter, 12 inches stroke, double-acting, cut-off at one-third stroke.
Boiler Pressure 105 lbs. absolute per square inch.
Speed 7,500 revolutions per hour = 125 per minute. 3,000 revolutions per run occupying 21 minutes.

Second series of Ten Runs = 210 minutes net.

Run.	High-p. Annulus.		Heater.	Intermediate (hot-cylinder bottom).					Steam Reservoir.	
				Inlet Temperature.						
	Terminal Pressure absolute.	Exhaust Temperature.	Steam Pressure absolute.	Actual.	Saturated.	Superheat.	Outlet Temperature.	Terminal Pressure absolute.	Steam Pressure absolute.	Temperature.
	Lbs.	Fahr.	Lbs.	Fahr.	Fahr.	Fahr.	Fahr.	Lbs.	Lbs.	Fahr.
1	60	280°	50	460°	281°	179°	310°	30	25	240°
2	56	278°	49	474°	280°	194°	318°	30	24	238°
3	52	276°	48	470°	278°	192°	352°	28	23	235°
4	52	276°	49	460°	280°	180°	350°	28	23	235°
5	53	274°	48	446°	278°	168°	348°	29	23	235°
6	52	274°	47	432°	277°	155°	342°	32	23	235°
7	52	272°	46	420°	276°	144°	336°	29	23	235°
8	54	272°	46	410°	276°	134°	328°	30	24	238°
9	52	270°	45	400°	274°	126°	308°	28	23	235°
10	52	270°	44	388°	273°	115°	302°	26	22	233°

TABLE 14 (*continued*).

SECOND SERIES OF TEN RUNS = 240 minutes net.

Run.	Low-pressure cylinder. Terminal Pressure absolute.	Condenser Vacuum. Inches of mercury.	Indicated Horse-Power. High-pressure annulus.	Intermediate bottom.	Low-pressure cylinder.	Total.	Water* consumed. Per hour.	Per I.H.P. per hour.
	Lbs. per sq. in.	Inches.	I.H.P.	I.H.P.	I.H.P.	I.H.P.	Lbs.	Lbs.
1	7·0	28	4·2	3·6	9·3	17·1	191·2	11·2
2	7·0	28	3·9	3·6	9·7	17·2	193·7	11·2
3	7·0	28	3·9	3·6	9·6	17·1	185·0	10·8
4	6·0	28	3 7	3·6	9·1	16·4	180·0	11·0
5	7·5	28	3 6	3·6	9 9	17·1	192 5	11·2
6	6·5	28	3·9	3·5	8·8	16·2	178·7	11·0
7	6 5	28	3 9	3·2	9 0	16 1	178·7	11·1
8	7·5	28	4·1	3 4	8·8	16 3	186·2	11·4
9	7·0	28	4·4	3·2	8·7	16·3	175·2	10 8
10	6·5	28	4·1	3·2	8·9	16·2	175·2	10·8

* Water used by experimental engine alone,
exclusive of donkey feed-pump and of water condensed in steam reservoir surrounding low-pressure cylinder.
Average result 11 lbs. per indicated horse-power per hour.

(Mr. Jeremiah Head.)

TABLE 15.—*Trials of Experimental Superheated-Steam Engine.* 21 March 1886. *See Plate* 41.

Saturated Steam in High-pressure annulus, 7½ and 10½ inches diameter, 9 inches stroke, cut-off at half-stroke.
Superheated Steam in Intermediate cylinder (hot-cylinder bottom), 10½ inches diameter, 9 inches stroke, cut-off at half-stroke.
Low-pressure cylinder, 12 inches diameter, 12 inches stroke, double-acting, cut-off at one-third stroke.
Boiler Pressure 105 lbs. absolute per square inch.
Speed 7,500 revolutions per hour = 125 per minute. 3,000 revolutions per run occupying 24 minutes.

Third series of Twelve Runs = 288 minutes net.

Run.	High-p. Annulus. Terminal Pressure absolute.	High-p. Annulus. Exhaust Temperature.	Heater. Steam Pressure absolute.	Intermediate (hot-cylinder bottom). Inlet Temperature. Actual.	Inlet Temperature. Saturated.	Inlet Temperature. Superheat.	Outlet Temperature.	Terminal Pressure absolute.	Steam Reservoir. Steam Pressure absolute.	Steam Reservoir. Temperature.
	Lbs.	Fahr.	Lbs.	Fahr.	Fahr.	Fahr.	Fahr.	Lbs.	Lbs.	Fahr.
1	54	274°	48	440°	278°	162°	300°	31	23	235°
2	58	278°	49	462°	280°	182°	332°	31	24	238°
3	53	276°	48	456°	278°	178°	352°	29	21	238°
4	54	274°	48	446°	278°	168°	340°	28	21	238°
5	53	274°	46	432°	276°	156°	326°	28	23	235°
6	54	272°	46	416°	276°	140°	286°	27	24	238°
7	52	272°	46	406°	276°	130°	304°	28	22	233°
8	53	270°	45	394°	274°	120°	308°	28	23	235°
9	57	270°	45	374°	274°	100°	261°	28	23	235°
10	52	270°	43	370°	271°	99°	262°	26	22	233°
11	52	268°	42	360°	270°	90°	258°	27	22	233°
12	50	266°	42	350°	270°	80°	260°	27	22	233°

TABLE 15 (*continued*).

Third series of Twelve Runs = 288 minutes net.

Run.	Low-pressure cylinder. Terminal Pressure absolute.	Condenser Vacuum. Inches of mercury.	Indicated Horse-Power. High-pressure annulus.	Indicated Horse-Power. Inter-mediate bottom.	Indicated Horse-Power. Low-pressure cylinder.	Indicated Horse-Power. Total.	Water* consumed. Per hour.	Water* consumed. Per I.H.P. per hour.
	Lbs. per sq. in.	Inches.	I.H.P.	I.H.P.	I.H.P.	I.H.P.	Lbs.	Lbs.
1	6·5	28	3·9	3·4	9·2	16·5	187·5	11·3
2	6·5	28	3·8	4·0	9·7	17·5	193·7	11·0
3	7·0	28	4·1	3·5	9·3	16·9	177·2	10·5
4	7·0	28	3·9	3·5	8·8	16·2	186·2	11·5
5	6·5	28	4·0	3·4	9·0	16·4	201·2	12·2
6	7·0	28	4·3	3·2	9·0	16·5	192·5	11·6
7	6·5	28	4·0	3·2	9·0	16·2	188·7	11·6
8	6·5	28	4·5	3·0	8·6	16·1	168·7	10·4
9	7·0	28	4·5	2·9	9·6	17·0	196·2	11·5
10	7·0	28	4·3	3·0	9·4	16·7	188·7	11·3
11	7·0	28	4·0	2·7	9·2	15·9	185·0	11·6
12	6·5	28	4·1	2·7	9·0	15·8	178·7	11·4

* Water used by experimental engine alone,
exclusive of donkey feed-pump and of water condensed in steam reservoir surrounding low-pressure cylinder.

Average result 11·3 lbs. per indicated horse-power per hour.

(Mr. Jeremiah Head.)

all become saturated when it reached the reservoir R. From the reservoir the steam passed into either end of the second or low-pressure cylinder through an ordinary slide-valve worked by an eccentric, being cut off at one-third of the stroke and expanded down to 6½ lbs. absolute pressure into the surface condenser, which maintained a vacuum of 28 inches of mercury. It might have been expected that, as the saturated steam was at the outset passed direct from the boiler into the annulus of the first cylinder, and was exhausted thence before being superheated, some water of condensation would be found in the bottom of the heater. But this was not the case, and it was always perfectly dry. In the reservoir R however there was always water after each run, confirming the idea that the superheated steam had again become saturated by that time, and showing that the 165° of superheat was not sufficient under those conditions to carry the steam to the end of its journey in a dry state. After ten runs of 3,000 revolutions each, as far as he remembered about 40 lbs. of water had been taken out of the reservoir; it was tapped off after each run. A brake K was fitted on the further end of the crank-shaft; and indicator diagrams were taken at intervals for determining the horse-power. The high-pressure annulus gave an average of 4 I.H.P.; the intermediate cylinder, being the bottom of the high-pressure cylinder, gave 3½ I.H.P.; and the low-pressure cylinder with its two ends gave 9 I.H.P., making a total of 16½ I.H.P. The water consumed, as measured by the condensed water drawn from the condenser, was 11 lbs. per I.H.P. per hour; but adding the water drawn off from the reservoir R it was increased to 11·6 lbs. With regard to the superheater the intention was, if the plan had come to be a commercial success, to employ two working alternately, since it took a considerable length of time to heat up the mass of fire-brick; but after it was heated up it lasted a considerable time. By having them in duplicate, one could have been firing up while the other was in use, according to the recognised Siemens method. Although this superheater and engine had simply remained an experimental apparatus, he thought it was desirable that, if commercially it was going to pass into oblivion, it should not be unrecorded in the Institution Proceedings.

Mr. E. Tremlett Carter asked whether in the experiments just described by Mr. Head any evidence had been found of water-gas being produced by the dissociation of the steam in the superheater. If brickwork was heated up by a furnace to a white heat, there would be a certain amount of soot deposited upon it; and if steam was brought into contact with the white-hot brickwork, it would undergo a natural dissociation, and a certain amount of water-gas would pass off in the steam and escape unused. Any evidence on this point would therefore have an important bearing upon the practicability of superheating steam by the plan of bringing it into contact with brickwork which had been previously heated by direct flame or hot gases. If water-gas were produced, it would make its way with the steam through the engine into the condenser, and would be discharged by the air-pump.

Mr. Head replied that he had not found any evidence of such an occurrence, not having been particularly on the look-out for it. There was a large condenser with an air-pump; but it was ten years ago that the experiments had been made, and he could not tell with certainty that no water-gas had been produced, though he had not noticed any such discharge from the air-pump.

Lt.-Colonel Thomas English believed it had been found by actual experiments lately made that no dissociation of steam took place under about 800° C. or 1,500° F.

Mr. Mark Robinson asked whether any record existed of the number of heat units put into the steam by means of the fire-brick superheater tried in the interesting experiments which had been described by Mr. Head.

Mr. Head was not aware that the observations made in the experiments had been worked out more closely than he had mentioned. The exact records of the second and third series of runs, in the ten series constituting the complete experiments, were given in Tables 14 and 15 (pages 202–5); and the heat units could

(Mr. Jeremiah Head.)

be worked out approximately from the temperatures and water consumption here recorded.

Mr. HUGH MCPHAIL was indebted to Professor Unwin's remarks (page 190) for the opportunity they afforded him of referring to one or two of the special points which were connected with his own superheating apparatus, and which had an important bearing on the whole question of superheating. It had been urged (page 191) that he had not dealt with the economy of superheating in the engine cylinder; and that his apparatus, if it was a superheater, was so by accident and not by design (page 190). These allegations he thought were contradictory. In the apparatus in use with the boilers at Maiden Lane the steam was heated from 362° Fahr., which was its temperature before entering the superheater, up to 650°, the temperature at which it left the superheater. These temperatures had been taken by the Burstall thermometer. Here was a superheat of 288° in refutation of the opinion that the apparatus was practically not a superheater. It rested with the engineers using the superheaters to do what they liked with the superheat after they had obtained it; for instance, at the Thornliebank Co.'s works the steam was now being used at 234° superheat (page 144) after passing through the boiler twice. This was double the superheat of from 100° to 120° considered sufficient by Professor Unwin (page 187). The superheat could either be passed back into the water of the boiler, and used there for evaporating; or it could be kept in the steam, to be carried forward by the steam into the engine. Engineers were so well aware of the economy gained by using superheated steam in the cylinder, and this part of the subject had been so ably dealt with by Professor Unwin (page 193), that it need not be further enlarged upon now. What he understood to be the problem before engineers was, how to generate superheated steam free from the risks which had hitherto prevented it from being used with practical advantage. Owing to the previous want of control over the superheat, the steam might at one time be nearly at red heat, and at another time might even be condensed; in his own experience the latter was often actually the case, when there were no means of regulating the heat. The

complete control of the superheat by his own apparatus enabled superheated steam now to be successfully used without fear of cutting the cylinders and valve-faces. In view of the notion (pages 176 and 190) that the apparatus was only by accident a superheater, it might be mentioned that in 1888 he had had occasion to make a superheater for chemical manufacturing purposes, which would of itself automatically regulate the temperature of the superheated steam. Various arrangements were made, some of which were original, while others were such as had been tried before. Superheating in itself was nothing new or difficult; but his object had been to bring the temperature of the steam under control, and to maintain it uniform; and this he had succeeded in doing. The amount of superheat he wished to obtain in 1888 was 280°, and the method he then adopted was a success, and gave no trouble or anxiety. By that method superheated steam was at the present time being produced sufficiently high in temperature for all purposes for which it had been adopted. That it had not been applied in engine use at the high temperature advocated by some engineers was due to the fact that manufacturers were naturally influenced by the former experience of the evil effects of superheated steam in engines, and they wisely moved with caution. In practice the perfect superheating of steam by his method was attained in the manner already described in the paper. Saturated steam was conveyed in pipes from the steam space of the boiler to a superheater affixed to the back end of the boiler, or as near thereto as possible; and the amount of heat transferred to the steam from the furnace gases was dependent upon the temperature of the gases passing around the superheater, and upon the flow of steam through it. After being thus superheated, the steam was passed through copper pipes in the water space of the boiler, where it gave up nearly all its superheat by radiation to the water. Thence it passed into a second superheater similar to the first; and on entering this second superheater it had always in practice been found to be dry, and therefore in a better condition for absorbing heat from the furnace gases as it passed through the second heater. It accordingly left the second superheater at a higher temperature than from any other superheater

(Mr. Hugh McPhail.)
yet introduced that was dependent for its heat upon the furnace gases of the boiler to which it was affixed. From the second superheater the steam could either be taken straight away to be utilized, or could be passed through the boiler again so as to control and regulate its temperature. The regulation temperature of the steam leaving the stop valve of a Lancashire boiler working at 100 to 150 lbs. pressure per square inch could be arranged to be from 400° to 700° Fahr. At Maiden Lane it would be remembered that there was only one superheater attached to the boiler, instead of two (page 150); and the temperature of the gases leaving the boiler was given at 654° Fahr. (page 156). As this apparatus was now fairly well known, and was appreciated by a large number of steam users, to whom it was supplying steam for over 50,000 H.P., it was needless to say more about its being a superheater, beyond emphasizing the important fact that, when combined with any kind of generator, it produced steam of a temperature above that normal to the pressure. The combination with the Lancashire boiler had about 70 per cent. more heating surface than the boiler by itself. As the principle of generating steam by passing the superheated steam through pipes in the water space of the boiler had sometimes been questioned, he had had a boiler 30 feet long and 8 feet diameter specially made in 1889, having only a single flue, which was jacketed. The steam generated within the boiler passed into the jacket on the flue, circulated through the superheaters, and then through the radiating pipes in the water space of the boiler, and was the sole medium of carrying the heat into the water for the generation of the steam therein. The results were highly satisfactory, and confirmed the principle he wished to establish; it was an expensive experiment, which repaid itself. This boiler had been constructed for a working pressure of 150 lbs., and with a slight improvement on the original design had been in use day and night continuously for five years. The superheating apparatus had been fitted to the boilers of a steamer of 5,000 tons, in which the interesting experiment had been tried of substituting steel radiating pipes, instead of copper, inside the boiler. Each boiler had a single superheater. A trial trip was made from

Leith to Hamburg with a saving of 18½ per cent. After a number of trips the engine cylinders were found to be in perfect order. Afterwards it was found that the steel pipes in the boiler were corroding, and for safety they had to be taken out. The occasion of taking them out presented an opportunity of trying the superheated steam direct to the engines, as had been done forty years ago, and as now recommended by Professor Unwin (page 191); and the result was that after only a single voyage troubles of the old kind began to appear, and the engine cylinders had to be bored out again. This demonstrated within his own experience that superheaters of the old kind were still attended with all the evil consequences which had accompanied their use in former times; and it left no room for doubt as to the superiority of his improved mode of regulating the temperature by means of the radiating pipes inside the boiler. In another instance this plan had now been working with a superheat of 140° Fahr. for four years without the slightest evil effect or repair. The conditions essential to the successful working of superheaters he considered had thus been solved in a way that removed all anxiety about the steam after it had been passed through this apparatus, while with other superheaters that anxiety could not be got rid of. So far as a clear exposition was required of the reasons for the saving obtained by superheating and of the causes of previous failure, it had been his endeavour to meet this requirement; and he considered he had succeeded in doing so.

Mr. Lavington E. Fletcher said the Manchester Steam Users' Association had tested both McPhail's and Musgrave's superheaters. In these tests McPhail's superheater affected the efficiency of the boiler rather than that of the engine, the superheat being nearly all absorbed by the boiler, and little, if any, passing over to the engine; but, however little passed over, it gave the engine the advantage of dry steam and tended to promote economy. Musgrave's superheater affected the efficiency of the engine directly, and did not affect that of the boiler otherwise than by reducing the consumption of steam by the engine, and thus lightening the duty the boiler had to perform.

(*continued on page* 216.)

(Mr. Lavington E. Fletcher.)

TABLE 16 (*continued to page* 215).

Tests of three Lancashire Boilers

WITHOUT *and* WITH *Musgrave and Dixon's Superheaters,*

at Messrs. J. Musgrave and Sons' Atlas Mills, Bolton.

See Plate 33.

WITHOUT or WITH Superheaters		WITHOUT	WITH
Date of tests	1895 September	11–12	4–5
Duration of tests	hours	6·36	6·25
Heating surface of each boiler, average	sq. feet	1,058	1,058
,, ,, each superheater, average	sq. feet		140
,, ,, economiser, 384 pipes	sq. feet	4,128	4,128
Fire-grate area per boiler	sq. feet	38	38
Boiler heating surface per sq. ft. of fire-grate	sq. feet	27·84	27·84
Draught entering economiser	water gauge, inch	$\frac{11}{16}$ to $\frac{3}{4}$	$\frac{9}{16}$
,, leaving ,,	water gauge, inch	1 to $1\frac{1}{4}$	$\frac{7}{8}$
Mean Temperature of atmosphere	Fahr.	60·0°	60·0°
,, ,, flue gases entering economiser,	Fahr.	614·0°	593·5°
,, ,, ,, ,, leaving ,,	Fahr.	384·0°	379·9°
Fall in temperature of flue gases	Fahr.	230·0°	213·6°
Mean Temperature of feed-water entering economiser,	Fahr.	108·5°	110·5°
,, ,, ,, leaving ,,	Fahr.	266·3°	277·5°
Rise in temperature of feed-water	Fahr.	157·8°	167·0°
Mean Steam-Pressure per square inch above atm.	lbs.	93·8	93·6
Mean Temperature of steam entering superheater	Fahr.		330·0°
,, ,, ,, leaving ,,	Fahr.		530·0°
,, ,, ,, leaving boiler-house	Fahr.		496·5°
,, ,, ,, near engines	Fahr.		463·0°
Rise in temp. of steam in passing superheater	Fahr.		200·0°
Fall ,, ,, between superheater and engines,	Fahr.		67·0°
Mean Superheat in steam near engines	Fahr.		133·0°
Calorific value of 1 lb. of dry coal	Th. U.	13,746	14,171
Theoretical Evaporation of 1 lb. of dry coal from and at 212° Fahr.	lbs.	14·24	14·68

TABLE 16 (*continued from preceding page*).

Tests of three Lancashire Boilers

WITHOUT *and* WITH *Musgrave and Dixon's Superheaters,*

at Messrs. J. Musgrave and Sons' Atlas Mills, Bolton.

See Plate 33.

WITHOUT or WITH Superheaters			WITHOUT	WITH
Coal Burnt in relation to boilers.				
Total during test	as used	lbs.	19,836	17,714
	dry	lbs.	18,566	16,218
	pure and dry	lbs.	15,834	13,498
Ash and clinker due to test		lbs.	2,732	2,720
		per cent.	13·77	15·34
Moisture in coal burnt		lbs.	1,270	1,496
		per cent.	6·40	8·41
Per boiler per week of 56 hours including 4 tons for banking &c.		tons	30·00	27·65
Per boiler per hour	as used	lbs.	1,039·23	946·00
	dry	lbs.	972·79	866·70
	pure and dry	lbs.	829·14	721·65
Per hour, as used, per sq. foot of	boiler heating surface	lb.	0·98	0·89
	fire-grate	lbs.	27·35	24·89
Water Evaporated from temperature of feed.				
Total during test		cubic feet	2,305·87	1,926·25
		lbs.	142,659	119,173
Per boiler per hour		cubic feet	120·79	102·76
		lbs.	7,473·23	6,358·17
Per hour per sq. foot of	boiler heating surface	lbs.	7·06	6·01
	fire-grate	lbs.	196·66	167·32
Per lb. of coal	as used	lbs.	7·19	6·72
	dry	lbs.	7·68	7·34
	pure and dry	lbs.	9·01	8·82
Equivalent Evaporation from and at 212° Fahr.				
Per lb. of coal as used	boilers alone	lbs.	7·06	6·52
	boilers and economiser	lbs.	8·23	7·68
Per lb. of coal dry	boilers alone	lbs.	7·54	7·13
	boilers and economiser	lbs.	8·80	8·40
Per lb. of coal pure and dry	boilers alone	lbs.	8·85	8·56
	boilers and economiser	lbs.	10·32	10·08
Calorific value realized.				
Boilers alone		per cent.	52·96	48·59
Boilers and Economiser		per cent.	61·77	57·24

(Mr. Lavington E. Fletcher.)

TABLE 16 (*continued from preceding page*).

Tests of three Lancashire Boilers

Without *and* With *Musgrave and Dixon's Superheaters,*

at Messrs. J. Musgrave and Sons' Atlas Mills, Bolton.

See Plate 33.

Without or With Superheaters		Without	With
Engines.			
Mean Speed, revolutions per minute	revs.	57·33	57·00
Average initial Pressure absolute per sq. inch — High-pressure pistons	lbs.	105·75	104·21
Average initial Pressure absolute per sq. inch — Low-pressure "	lbs.	12·20	11·93
Average mean effective Pressure per sq. inch — High-pressure pistons	lbs.	46·80	47·96
Average mean effective Pressure per sq. inch — Low-pressure "	lbs.	4·68	4·22
Equivalent mean effective Pressure per sq. inch referred to Low-pressure pistons	lbs.	17·50	17·37
Mean Temperature of — Injection water	Fahr.	86·1°	92·5°
Mean Temperature of — Ejection "	Fahr.	109·9°	112·8°
Rise in temperature of condensing water	Fahr.	23·8°	20·3°
Mean Vacuum per square inch in — cylinders	lbs.	10·90	11·07
Mean Vacuum per square inch in — condensers	lbs.	12·31	12·30
Barometric Pressure per square inch	lbs.	14·60	14·71
Average Horse-Power developed	I.H.P.	1,223·5	1,207·5
Steam.			
Moisture in steam leaving boiler-house, by calorimeter	per cent.	3·02	
Steam generated in boilers	lbs.	142,659	119,173
Steam lost by leakage at stop-valves, safety-valve waste-pipes, &c.	lbs.	235	88
Steam condensed in pipes, and caught at separators	lbs.	1,768	
Steam condensed in pipes to dynamo-engines, steam-kettle &c.	lbs.		798
* *Steam supplied to engines.*			
Total	lbs.	140,656	118,287
Per hour	lbs.	22,105	18,933
Per I.H.P. per hour	lbs.	**18·06**	**15·68**

* Including steam supplied to Meldrum blowers, to donkey pump, and to small engine driving economiser scrapers; but deducting steam condensed in pipes and otherwise lost.

TABLE 16 (*concluded from page* 212).

Tests of three Lancashire Boilers

Without *and* With *Musgrave and Dixon's Superheaters,*

at Messrs. J. Musgrave and Sons' Atlas Mills, Bolton.

See Plate 33.

Without or With Superheaters			Without	With
Coal Burnt in relation to engines.				
*Per hour in raising steam supplied to engines	as used	lbs.	3,074·76	2,818·53
	dry	lbs.	2,878·17	2,582·32
	pure and dry	lbs.	2,454·12	2,150·12
†Per I.H.P. per hour, gross	as used	lbs.	2·54	2·33
	dry	lbs.	2·38	2·14
	pure and dry	lbs.	2·03	1·78
*Per I.H.P. per hour, net	as used	lbs.	2·51	2·33
	dry	lbs.	2·35	2·14
	pure and dry	lbs.	2·00	1·78
Water supplied to boilers.				
Per hour		lbs.	22,420	18,947
Per I.H.P. per hour		lbs.	18·32	15·69
Steam accounted for by indicator diagrams.				
High-pressure cylinders	per hour	lbs.	16,555	15,903
	per I.H.P. per hour	lbs.	13·53	13·17
	percentage	per cent.	73·82	83·99
Low-pressure cylinders	per hour	lbs.	14,982	13,946
	per I.H.P. per hour	lbs.	12·24	11·55
	percentage	per cent.	66·81	73·66

* Deducting coal burnt in generating steam condensed in pipes and otherwise lost.

† Including all coal burnt in evaporating total water fed into boilers.

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The Musgrave superheaters, which were tested at the works of Messrs. John Musgrave and Sons, Atlas Mills, Bolton, in September 1895, were placed in the flame downtake at the back of the boiler, and consisted each of 26 pendant U-shaped tubes. The boilers were three in number in a range of five, all of the Lancashire type, 30 feet long by 8 feet diameter in the shell and 3 ft. 2 ins. diameter in the furnaces. A superheater was attached to each boiler. Each furnace was fitted with a Meldrum blower, which was used throughout the tests. There was a Green economiser containing 384 pipes; this was a large number of pipes for three boilers, the economiser having been put in for the whole range of five. The engines were a pair of horizontal tandem Corliss compound condensing engines, having cylinders $24\frac{3}{16}$ inches and $46\frac{3}{16}$ inches diameter and 6 feet stroke, giving a proportionate capacity of 1 to 3·65.

The particulars of the tests were given in Table 16 (pages 212–215). In conducting the tests the quantity of water pumped into the boilers was arrived at by direct measurement in tanks, not by meter; the quantity of coal burnt was ascertained by weighing it throughout the tests, not by referring to the books; and the temperature of the steam, both on entering and leaving the superheaters and on arriving at the engines, as well as the temperature of the furnace gases on entering and leaving the economiser, was taken in each case by a mercurial thermometer; the thermometers for taking the temperature of the steam were specially tested, and those for taking the temperature of the gases were of the nitrogen kind. Indicator diagrams were taken at both ends of each cylinder every half-hour.

The saving effected was as follows:—

In steam, per I.H.P.	14·35 per cent.
In coal "pure and dry," per I.H.P. . . .	12·30 „
In coal "as used," per I.H.P.	8·26 „

This was not a high result, nor as high as it was often supposed would be achieved by superheating. It would be seen that the saving in coal was less than the saving in steam: whence it appeared that the superheater to a certain extent robbed the boiler and economiser.

That robbery however paid: for, although the boiler did a little less work per pound of coal burnt, the engine did more. It seemed to be a question needing further investigation, how far the superheating could be pushed without neutralising its advantage by diminishing the efficiency of the boiler. The heating surface in the superheater was only 1 to $7\frac{1}{2}$ in the boiler; and his impression was that a better result would be obtained if the amount of heating surface in the superheater were increased.

Mr. William Schönheyder wished to emphasize the statement of Professor Unwin (page 192) that the bottom of the chimney was the right place for a feed-water heater or economiser, and that the hottest part of the boiler flues was the right place for a superheater. For superheating, he considered so high a temperature was wanted that the superheater ought to be placed over a separate furnace; and the furnace ought to be so arranged that its products of combustion could in the ordinary way be led under the superheater, but when not quite so much superheat was required a portion of them could be taken directly into the flues of the main boiler. This he thought was the more necessary, because, in starting a new engine with valves not yet faced up, it was likely that not the whole of the available superheat could be used, and it might therefore be desired to reduce it. By merely reducing the quantity of steam passing through the superheater, the latter might itself be readily overheated. Moreover if the oil used to lubricate the engine happened not to be the quality that it ought to be, it might be found that the engine was becoming scored, and the temperature would then require to be reduced. Surely with such high temperatures as were required in superheating, and with the furnace heat on the outside of the superheating pipes and the steam passing through them inside, the pipes must necessarily deteriorate. Although this had not been found so hitherto in the experiments quoted in the paper, it was simply because the amount of superheating was so slight. To get high economy high temperatures were wanted; and therefore on any large scale he thought it would be found of advantage to have a separate furnace under the superheater.

Mr. Patchell said it had been remarked by Mr. Longridge (page 169) and other speakers that a small degree of superheating could not produce any appreciable benefit, and that a saving of 20 per cent., for instance, could not be credited to superheating practically dry steam. Perhaps not. Practically dry steam was like liquid oxygen, very scarce at present; and engineers did not get enough of it in practice to enable them to sample it fairly. But there was abundant evidence, he thought, from figures in the paper, from Professor Kennedy's Edinburgh tests, and from other trials, that such savings were realised, and that appreciable results were obtained from slightly superheating what in common practice was considered to be dry steam.

The confused state of the subject, and the uncertainty as to the degree of economy to be obtained, had been referred to by Mr. Davey (178), with whom he agreed that it was deplorable; and he thought it would only be settled by some systematic sets of experiments with various sorts of superheaters, various degrees of superheat, and on various kinds of engines. Superheat might be employed efficiently, either in evaporating water in the boiler, as was done to various degrees in the McPhail apparatus; or it might be used to counteract radiation from steam pipes, or radiation and condensation losses in the cylinder; or even in some cases in the low-pressure cylinder only of a compound engine. It was obviously impossible to foretell the results to be obtained in one case from an experiment in another: just as, in a boiler of an entirely new kind, the effect of its heating surface could not be known till it had been tried; and the results obtained were then applicable only to another boiler or heating surface of the same class. So with superheating: when good results had been obtained in one case and in another yet better, the latter were apt to be criticised as exceptional or impossible, simply through lack of appreciating that the circumstances under which the tests were made were different. Such a lack of appreciation was apparent in Mr. Raworth's remarks (page 176) as to the McPhail superheater being only accidentally a superheater. This seemed a bold assertion truly, in the face of the figures given in the paper respecting the performance of this superheater at the various works at which it was in use.

The results of the Edinburgh trials, contributed by Professor Kennedy (page 166), were most interesting, and showed plainly the efficacy of small degrees of superheating. The 38 to 47 lbs. of coal burnt per square foot of grate per hour was a heavy consumption for a draught of only 0·53 inch of water. Probably either the coal was soft, or a good deal of it might have fallen through the fire-bars, the boilers being fired he believed by mechanical stokers. If the latter assumption was correct, it would impair the boiler efficiency, which he was somewhat disappointed with, having hoped to learn that it was higher, considering the boilers were dry-back marine boilers and were surrounded by the hot gases. To the careful covering of steam-pipe flanges he was glad to hear special attention called (page 168), as it was sadly neglected at present.

In Table 13 Mr. Longridge had given a highly instructive and useful analysis of efficient design. He was much obliged to him for including the Schmidt apparatus, which he regretted he had himself missed. He had also to thank Professor Schröter for copies of tests of the same apparatus, received from him after the paper had been read. The temperature of the steam in Table 2 had been taken in the main steam-pipe, so that Mr. Longridge was right in supposing it was that of the combined steam (page 171). In pointing out that some control must be exercised over the temperature of the steam (page 175), Mr. Longridge had put his finger on a weak spot in the construction of every superheater with which he was acquainted except McPhail's. A damper to control the gases had been introduced by Hirn in 1856, as Mr. Longridge was probably aware; but it had not the fascinating electrical arrangement to make it automatic, as recommended by the latter.

With regard to the tests in Table 6, made by Professor Kennedy, Mr. Raworth was right in presuming (page 177) that the cold feed had been allowed for in the figures given for the boiler efficiencies. In drawing attention in page 150 to the fact of the feed being cold, the point which he had wished to emphasize was that, if under certain conditions with cold feed a boiler efficiency of say 70 per cent. was obtained, then under the same conditions but with hot feed a greater efficiency would be obtained, after making all proper

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allowances for temperatures. This point seemed to him not to have been generally noticed; but it was clearly shown in experiments by M. Normand and Mr. Druitt Halpin.

Having endeavoured to adhere as closely to the title of the paper as the information at his disposal permitted, rather than to enlarge on the uses of superheated steam, he hardly understood the position which Professor Unwin had sought to take up in his remarks (pages 186–193). The paper contained all the details he had been able to get of the various superheaters, and the drawings by which they were illustrated had been kindly furnished by the several makers of the apparatus described. He had also endeavoured to get information as to the practical working of superheating apparatus, and especially as to any failures, from the engineers of the leading boiler-insurance companies, and from any users of such apparatus whom he had been able to discover; and he was indebted to Messrs. Crosland, Fletcher, Hiller, Longridge, and many others, for their kind replies to his enquiries. As to ignoring Hirn and his work (page 189), he had the highest appreciation of the work Hirn did, and had emphasized the fact in page 156 of the paper in no uncertain way; he regretted that this passage seemed to have escaped Professor Unwin's notice in reading the paper. As he was himself unfortunately debarred from studying the proceedings of German societies and other journals in that language, and as he had felt that the notes constituting the paper would be incomplete without particulars of Hirn and Schwoerer's work, he had applied to Professor Unwin for some data, as he knew he had studied the matter in Alsace. By his kindness he had been furnished with some results of tests, and had been referred to his report, alluded to by Mr. Longridge (page 169), on the Schwoerer superheater, which he had tested for the Exploration Co. From the reports of tests he found with regret that the particulars of the superheaters themselves were omitted, although the use of superheated steam was dealt with fully. To the construction of the apparatus the baldest possible allusion was made, without any data of dimensions; and it was much to be regretted that Professor Unwin had not taken this opportunity of supplying such data as he asked others to give. It was difficult too to reconcile

a disclaimer of a boiler gain due to superheating (page 187) with the statement that, if a superheating surface were added to a boiler, it would evaporate more water (page 191). Superheating tubes could evaporate only such water as might be carried over into them by the steam; they were not water heating or evaporating surfaces. Classifying the McPhail apparatus with other superheaters (page 190) was inevitable in the paper, unless all the others had been omitted for the reason stated in the concluding paragraph (page 160); but some pains had been taken to show how it differed from all the others.

The McPhail superheater he need not defend at length, after what had been heard of it from the inventor (pages 181 and 208); but he wished to insist on the fact that with it the gain was either a boiler gain or an engine gain or both, as was determined beforehand when designing the apparatus. Also, in view of the facts contained in the paper, there was no more justification for objecting that in using this superheater the temperature of the steam was first raised and then lowered again for no useful end (page 190), than there would be for suggesting that it was idle to generate steam at 160 lbs. pressure and then exhaust it at 5 lbs. from an engine. Both operations were attended with a genuine gain; and if it were known that there was a saving of 30 per cent. to be realised by the former of these operations, the sooner such a mode of superheating was adopted the better. With reference to the regulation or control of the superheat in the test made on 2nd January 1896, Table 8, the temperature at the steam stop-valve had been taken every five minutes, the highest observation being 417° Fahr. and the lowest 374°. Only one instance was noticed of each of these extreme readings; the general readings were from 395° to 405°. It would be remembered that this was with only one-half of McPhail's complete apparatus.

Ready and reliable instruments at moderate prices, for showing the temperature of the superheated steam and of the escaping gases (page 197), and also the state of the latter (page 190), he agreed would be a valuable acquisition in the boiler room. The temperatures could now be measured readily by the Burstall pyrometer, which he

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felt sure would soon come into extensive use; but the state of the gases could not be ascertained, except by some chemical method. It must however be some simple plan, because stokers were rather fastidious, and would immediately want an increase of pay if they had to watch a chemical balance or a wash-bottle.

The experimental engine and superheater designed by Mr. Perrett (page 199) and tested by Mr. Head (page 200) were highly interesting. With the separate furnace however for the superheater it was hardly fair for the performance of the engine to be stated only in steam consumption, thereby neglecting the value of the heat obtained from the coal burnt in firing the superheater by a separate furnace, as hinted in Mr. Mark Robinson's enquiry (page 207). In consequence of the steam being turned immediately through the fire-brick passages where the gases of combustion had been, he should have been rather afraid of the dust being carried through from the superheater into the engine. Although in the experimental trials he understood the engine had made a large number of runs of 3,000 revolutions each, he should have thought that with such a mode of superheating the cylinder would be likely to become scored in continuous working without stopping.

Having again looked up Mr. Wethered's paper, to which Mr. Halpin had drawn attention, he found that, as stated in page 137, he claimed in 1860 to have introduced combined steam four years previously. But in patent No. 1,285 dated 25 May 1853, in the name of W. E. Newton, he found that combined steam had been used with a 12-H.P. engine; and the particulars were given of the pipes employed, and other details.

The further particulars asked for by Mr. Donkin with regard to the size of the superheaters he would try to obtain. In return he hoped Mr. Donkin would himself give the Institution some tests of the Gehre apparatus in England, with which his name had been connected.

He thanked Mr. Fletcher for supplementing the paper with the tests he had recorded of the Musgrave superheater (pages 211–217). A comparison of Tables 2 and 16 was interesting in connection with the question as to how far superheating could in this instance be

pushed with advantage. As the McPhail superheater was the one he had himself used, it had naturally been the one he had most fully dealt with in the paper.

The best position for placing the superheater, he agreed with Professor Unwin and Mr. Schönheyder, was certainly in the hottest gases from the furnace. If placed anywhere else, it would be more cumbrous and less efficient. He could hardly agree with Mr. Schönheyder's opinion (page 217) that the reason why the superheating pipes had not deteriorated was because the degree of superheating was so slight. The fact must have been overlooked that the temperature of the steam in the pipes was some 600° Fahr.; and that opinion must have been based on the temperature of the steam as it left the boiler after passing through the radiating pipes. After an experience with two superheaters, which had each worked more than the equivalent of three years at ordinary factory hours without a hitch or any signs of deterioration with steam in the tubes of 600° Fahr. and over, he thought he was justified in saying with confidence, not only that the back of the furnace was the fittest and most economical position for the superheater, but that this position presented no dangers. Deterioration under the circumstances was no more necessary or rapid than it was in an ordinary fire-box.

In acknowledging the honour of having been asked to read these notes before the Institution, he hoped his efforts might in some small degree promote the advancement and more general adoption of superheated steam, which could not fail to be accelerated by the full discussion that had been elicited by the paper.

The President was sure the members would agree with him in passing a hearty vote of thanks to Mr. Patchell for his valuable contribution to the proceedings of the Institution. He hoped also that the author's remarks in the discussion would induce Professor Unwin to give the fullest possible particulars as to the successful economical results obtained in Alsace.

Mr. William H. Booth wrote that the author's conclusions relative to the injurious effect of alternations of saturated and superheated steam were particularly interesting, and he should be glad to hear what explanation could be offered as to the nature and cause of this trouble. This was the more important in face of the possibility of a flue superheater acting as a condenser, in the event of a great inrush of cold air by way of the furnaces. He desired to emphasize the necessity of providing by-passes for the flue gases, when the steam is not flowing through the superheater pipes. The experience of the author and others during the past year or two appears to be strongly in favour of the view that steam when moving is an efficient means of absorbing heat from fire-heated pipes; and to many engineers the durability of superheater pipes has come rather as a surprise. The remarkable results obtained with the McPhail apparatus in increasing the efficiency of steam boilers have been received with considerable doubt; and the writer has himself made special enquiries from reliable engineers in Lancashire, who have informed him that these results have actually been obtained. They have thus furnished another proof of the efficiency of heating surface when applied in the form of a tubular superheater. It is satisfactory to find that the author's own experience fully corroborates the figures obtained elsewhere. Especially is line 8 of Table 6 (page 151) to be noted, showing the great increase in the capacity of the boiler by superheating. Hitherto priming has been looked on as a serious fault in a steam boiler; but with superheaters in conjunction with boilers it would seem as though priming has become a virtue, being a means whereby thoroughly wet steam may be carried over to suitable evaporative surfaces, and be there converted into good dry steam. Priming has lost its terrors; and the importance is great of the figures in page 156 resulting from the combined effects of superheating and assisted draught. In this connection the writer thinks that sufficient attention has not yet been paid to the novel form of Solignac boiler recently described in L'Industrie Electrique (1895, pages 263–8), in which the whole of the evaporation is conducted in a series of tubes fed from a water drum by a fine jet, which is forced into each tube by a special circulating pump. It is perhaps a little unfortunate

that the results of using superheaters as evaporators have proved so good that to some extent the object of a superheater, namely actual superheating, has been rather pushed into the background. There can be little doubt that water, in whatever way it enters the cylinder of a steam engine, has a cumulative effect in promoting waste. If this were fully recognized, it would be as fully perceived that the reduction of wetness has also an economical effect greater than might be superficially apparent; and it follows that the quantity of heat to be added to steam bears only a small ratio to the amount of cylinder condensation: that in fact the amount of superheat need be little in excess of what is required to supply the heat which disappears as work during the expansive portion of the stroke. It is to be hoped that the author will follow up this paper with another dealing with the effect of superheating in the engines themselves, as soon as he can collate observed results; and that he will not rest satisfied with having overcome the priming difficulty, but will go on to reap the full benefit of superheating at the engine. The fact of the disappearance of so many degrees of superheat between the superheater and the engine in all recorded tests seems strong evidence that, where there is no superheat, the same loss of heat must occur, and must cause steam to be exceedingly wet; and the fault of wetness is just as serious as want of superheat, and with wet steam it can never be known how serious the fault really is; whereas, even if there be only a few degrees of superheat, it is known there can be no moisture present. It is likely that the large saving found to occur with only a small amount of superheat is sometimes to be credited to the absence of a previously large degree of wetness.

Mr. WILLIAM GEIPEL wrote that, although the paper does not deal quite so fully with superheating as could have been wished, yet it has at any rate brought forward several points of great interest; moreover it has been the means of eliciting from such authorities as Professor Kennedy and Professor Unwin information which is of the greatest interest and use, not only to the members of this Institution but to the great majority of engineers all over the world. Superheating the writer thinks should not be employed

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indiscriminately: at any rate not for all purposes to such a high limit as has been mentioned, without first thoroughly weighing the advantages against the disadvantages. Superheated steam he thinks it is generally acknowledged has materially less effect on the economy of high-speed than of low-speed engines; in fact Cotterill ("The Steam Engine," 1890, page 336) goes so far as to state that the initial condensation in a cylinder varies inversely as the square root of the speed of engines, showing how important is the bearing of speed on the advisability of superheating. The tests given in the paper seemingly go to prove this; for although unfortunately in none of the tables does the speed of the engines appear, yet it seems they were all slow-speed engines, with the one exception of the Willans engines used in the test recorded in Table 6, which shows much less saving. This point is noticed in the paper (pages 150–1), and the suggestion is made that it may be accounted for by the engine not being in such good order in the second test, with superheating, as in the first, without superheating. In the writer's opinion this explanation is wrong, and the result is entirely due to the use of a high-speed engine with a throttle-valve governor; if acting at all, the throttle-valve governor causes wire-drawing and consequent superheating. With slow-running engines, especially those which have Corliss or other automatic cut-off gear, the economy due to superheating is by no means overstated in the paper. Broadly speaking the writer thinks that superheating has less beneficial effect in multiple-expansion engines than in engines where the whole of the expansion takes place in one cylinder; at any rate the benefit is less where the multiple expansion reduces the range of temperature as it ought to do. Even in multiple-expansion engines it is undoubtedly of great importance that there should be no water in the cylinders; but it is possible that such engines may be more economically maintained dry by the use of automatic drain-valves or steam-traps, than by resorting to so high a degree of superheating as will serve for the whole period during which the steam is passing through the successive cylinders.

Another point which has also an important bearing on the economy of superheating is the increased loss by radiation and

conduction in the steam pipes and receivers. It is true that in those cases where the boilers and engines are near each other, as in marine engines, this loss may be insignificant compared with the advantages; but not so where the steam-pipe surface is considerable, as in central electric-light stations. The loss owing to these causes varies directly as the difference in temperature between the steam and the atmosphere. As previously pointed out by the writer (Proceedings October 1895, page 578), with saturated steam at 150 lbs. pressure per square inch this loss is as much as half a ton of coal per annum for every square foot of pipe surface uncovered which is in use during the whole year; or if lagged, one-third of this amount. Thus for a pipe surface of 1,000 square feet, which is certainly not much for a central station, the loss would amount to say 250 tons of coal per annum. If the steam were superheated even to the extent of 234° Fahr. of superheat, as mentioned in page 144, this loss would be nearly double. It would be interesting to know whether Professor Unwin, in estimating the saving of coal by superheating at 15 to 20 per cent., has included any deduction for this important source of loss. In such cases as the last, a certain amount of superheating has long been advocated by the writer: namely a sufficient amount to make up for the condensation in the pipes and to deliver dry saturated steam to the engine. Even in the case of high-speed engines this is desirable. It is not certain however whether this small amount of superheating cannot be obtained by simply working the boiler at a rather higher pressure, and throttling the steam at the stop-valve by means of an automatic reducing valve. The complication of pipes and joints inherent in superheaters would thereby be avoided; but where higher degrees of superheating are advisable, the plan would be impracticable. In the McPhail superheater the plan of first superheating the steam and then taking away the superheat by passing the steam again through the boiler seems but a make-shift arrangement. Reference is made in page 150 to the great increase in the capacity of the author's boiler since the adoption of this superheater; but before its adoption it appears from Table 6 that the boiler was doing far less than its capacity as rated by the makers, evaporating not more than 1·9 lb. of water per hour per square foot of

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heating surface. From Babcock and Wilcox boilers the writer has with ease got twice this duty, and more by forcing; while it is not apparent how the coal consumed per hour per square foot of grate was as low as 11·3 lbs., and how with the superheater 15·5 lbs. could be burned. Is not the better boiler efficiency at least partly attributable to the use of a thicker fire? Even 15·5 lbs. is a low rate of consumption, seeming to indicate abnormal conditions in the boiler arrangements, about which the author might perhaps be able to give further particulars.

Mr. Patchell regretted he was unable to supply a satisfactory explanation (page 224) as to the injurious effect of alternations of saturated and superheated steam, referred to in page 138. The experience however of the Hamburg and Leith steamer, mentioned by Mr. McPhail (page 211), showed that a simple flue superheater uncontrolled was still capable of repeating the old effects in a reasonably short time, although such effects had been entirely absent when the degree of superheat was regulated by the radiating pipes.

The suggestion of Mr. Geipel (page 226), that the small saving due to superheating on the Willans engine was occasioned by the superheat due to wire-drawing at the governor, would not suffice. The engine was run on each trial with the governor valve so wide open that wire-drawing was practically absent, and would not begin until the engine was running away. The degree of superheating which saturated steam underwent by wire-drawing was merely nominal, unless the fall in pressure was considerable. In multiple-expansion engines it would probably be more economical to re-heat the steam between the cylinders than to attempt to drain the water off by steam traps or valves, even if they discharged water only, which unfortunately they did not.

Mixing superheated steam from the two boilers at Maiden Lane had greatly diminished the discharge from the steam traps, and enabled some of them to be put out of action; as more superheaters were added, he hoped to work with the steam traps shut off entirely, except at starting or at times of low load, and to effect an economy thereby.

The evaporation given in Table 6 was practically the same as that daily obtained without excessive priming, which had been the limit to the duty before the superheater was fixed. Priming became a virtue, as aptly pointed out by Mr. Booth (page 224), after the superheater was fixed and full benefit could be taken of the available draught. Since the fan had been fixed, the evaporation, measured over periods of an hour or two, had frequently been at the rate of 12,000 lbs. an hour; but to quote such figures as the evaporation of a boiler was only misleading, as it could not be maintained in regular work over long periods.

STEEL STEAM-PIPES AND FITTINGS, AND BENARDOS ARC WELDING IN CONNECTION THEREWITH.

By Mr. SAMUEL MacCARTHY, of London.

The constantly increasing use of steam at high pressures, both for marine and land engines, renders the employment of the most suitable and reliable Steam-Pipes a matter of the utmost importance and interest to engineers; and it is somewhat surprising that the subject does not appear to have been brought before this Institution, for consideration and discussion, during so long a period.

Cast-Iron and Copper Pipes.—Cast-iron, which has the advantage of being seamless, and which can be moulded into any desired shape, is heavy, cumbrous, frequently porous, and always liable to fracture by a blow. The necessarily great thickness of cast-iron steam-pipes, and the rigidity of the bends, also add greatly to the difficulties of arranging for expansion. Hence the use of this material, for pressures over 50 or 60 lbs. per square inch, is becoming more and more rare. Copper, which for so long a period was almost exclusively adopted in the navy, and also to a great extent in the mercantile marine, for steam and feed-pipes, has, in consequence of numerous disastrous failures, become of late years greatly discredited. The causes of its failure need not be entered into here, inasmuch as the subject was fully dealt with in the paper on steam-pipes which was read by Mr. J. T. Milton before the Institution of Naval Architects in April 1895 (Transactions, vol. xxxvi, page 191).

Wrought-Iron and Steel Pipes.—Cast-iron and copper having failed to afford the necessary security and confidence in connection with steam at high pressures, there arose a great demand for welded wrought-iron or steel pipes; which was promptly met by the leading tube-makers, who lost no time in procuring the requisite machinery for their manufacture. With regard to the respective merits of iron and steel for this purpose, as for many others, there has always been a great difference of opinion among engineers; and the controversy is not yet at an end, but invites renewed experiment and useful discussion. In the early days of the manufacture of large welded steam-pipes, iron was most frequently preferred; and doubtless the preference was then wise, and was justified by experience, inasmuch as at that time the manufacture of steel plates had not reached the degree of perfection to which it has since attained. Not only were the steel plates often laminated and blistered, but it was difficult to procure mild steel of a suitable quality for welding. Happily these troubles have to a great extent disappeared; and an abundance of excellent mild steel can be obtained, which can be welded as readily as iron.

Corrosion.—One of the principal objections raised by the opponents of steel has been that it is more subject to corrosion than iron; and doubtless this would be a grave defect, if shown by experience to prevail. This matter was dealt with at great length in the paper on the comparative endurance of iron and mild steel when exposed to corrosive influences, which was read by Mr. David Phillips before the Institution of Civil Engineers in March 1881 (Proceedings, vol. lxv, page 73). As the result of numerous experiments, he came to the conclusion that steel, in the form either of boiler tubes or of plates, was greatly inferior to iron in power to resist corrosion; but in the lengthened discussion which followed, the speakers were almost unanimous in their dissent from this conclusion. At all events, whatever may be the result as regards boiler tubes, there is every reason to believe that welded steel steam-pipes are free from any risk in this respect. Recently the author has had an opportunity of examining several lengths of 7-inch steam-pipes and bends, made of steel, at the City of London electric lighting

station at Bankside, which have been constantly at work at a pressure of 160 lbs. for over three years, and which exhibit not the slightest appearance of pitting, scoring, or corrosion in any form. Although only an isolated case, this affords pretty strong evidence so far as it goes; and the author has never heard of a single complaint as regards corrosion of steel steam-pipes in connection with the large quantities which have been supplied. In erecting ranges of steam-pipes great care should be taken to ensure efficient drainage; for should there be any point in the range where the condensed water is allowed to lodge, corrosion will no doubt take place sooner or later at that part, whether the pipes are made of wrought-iron or of steel.

Thickness of Metal.—As to the comparative thickness of steel and iron pipes, it might naturally be expected that the former would be made lighter in proportion to the greater tensile strength of steel. Theoretically this should be so; but in practice it is carried out to only a limited extent. Not only is a large margin required for safety, but the exigencies of manufacture necessitate a certain thickness of plate to ensure making a sound weld; and this thickness cannot be reduced without risk. For instance, a common size of steam-pipe, 10 inches bore, is most conveniently made of $\frac{1}{4}$-inch plate, which would be amply strong enough for iron, and is consequently excessive for steel; but the reduction of 1–16th inch in the thickness would affect the cost and the weight so slightly, that it is thought best to err on the safe side. For larger sizes, of 12 to 18 inches bore, it is found practicable to make steel pipes somewhat lighter in proportion to iron. In this connection it is interesting to note that the Admiralty are now using steel for all sizes of steam-pipes over 2 inches bore. Above 9 inches bore they still adhere to the practice of having a butt strap or cover strip riveted along the line of weld, which the author believes to be worse than useless, as the numerous rivet-holes necessarily tend to weaken the pipe. It is also probable that the presence of the cover strip, in connection with the expansion of the pipe both circumferentially and longitudinally, has the effect of setting up a tearing strain, which may result in leakage at the rivets. The addition of the butt strap also adds greatly to the cost of the pipes. In a recent specification for steam-

pipes the Admiralty fix 3–8ths of an inch as the uniform thickness for all pipes from 6 to 14 inches diameter of bore, the tensile strength of the steel not to exceed 25 tons, and not to be less than 23 tons per square inch. In the following Table 1 are given the thicknesses which are usually specified for steam-pipes from 6 inches up to 18 inches bore, for pressures varying from 100 to 180 lbs. per square inch; also the corresponding hydraulic test-pressures. In

TABLE 1.

Thicknesses of Steel Steam-Pipes for varying pressures.

Diameter of Bore.	Steam Pressure, lbs. per square inch. 100	120	150	180
Inches.	Inch.	Inch.	Inch.	Inch.
6	1-4	1-4	1-4	1-4
7	..	..	..	..
8	..	..	..	..
9	..	..	..	5-16
10	..	..	..	..
11	..	..	5-16	..
12	..	5-16	..	..
13	5-16	..	..	..
14	..	..	..	3-8
15	..	..	..	..
16	..	..	3-8	..
17	..	..	..	..
18	..	..	..	..
	200	240	300	360
	Hydraulic Test-Pressure, lbs. per square inch.			

addition to the hydraulic test, the pipes are also tested with high-pressure steam. This is important, because they are thus tested under actual working conditions as regards temperature and consequent expansion; and any minute pin-hole which has not been revealed by the cold-water test is certain to be detected under steam.

Methods of Manufacture.—It is frequently supposed that the electric arc is brought into operation for welding the longitudinal seam of the barrel of the pipe. As a matter of fact this is not the case. It can of course be done, and has been done successfully in many instances; but as it was found from experience that no saving

in cost was effected, and that nothing was gained either in speed or in efficiency by the use of electricity for this purpose, the straight seams are still welded in the ordinary manner: namely, either in the rolls, or by gas and power.

Roll Welding.—In this process the iron or steel in the shape of strip is first scarfed along both edges in a planing machine, on the outer face along one edge and on the inner face along the other; it is then heated in a muffle, and by being drawn through skelping dies is bent into tubular form or skelp, and is ready for the welding furnace. When the welding heat is reached, the skelp is withdrawn from the furnace with tongs, as shown in Plate 43, and the end is placed upon the head of a horizontal mandril fixed to a long rod, which is held between a pair of revolving rolls that are turned to suit the particular size of tube being made. The skelp being seized by the rolls is rapidly welded by the pressure exerted upon it between the two rolls on the outside and the mandril on the inside of the tube. In all cases the tube is drawn twice through the rolls at a welding heat, the process being the same each time. On finally leaving the welding rolls, the tube passes through a manglo or reeling machine, which straightens it; the ends are then cut off square, and it is ready for testing.

Gas Welding.—The strips after being scarfed along their edges are heated only cherry red in a muffle, and are then bent to the required diameter in the rolls. The pipe is next placed on a "beak," as shown in Plate 44, and a jet of gas G, Fig. 4, is brought to bear along the seam, whereby in a short time, varying according to the thickness of the plate, a length of about 6 to 8 inches is brought to a welding heat. A small quick-speed steam-hammer fixed above the work then rapidly closes the seam, and completes the weld. The operation is repeated on the next length, until the longitudinal seam is completed. The use of gas renders the process clean, and absolutely free from dust and other impurities; and the edges of the pipe having been carefully freed from scale after leaving the heating furnace and rolls, a perfectly sound weld is obtained. At

some works all sizes of pipes are made through the rolls; while at others this method is followed only up to 8 inches bore, and all the larger sizes are welded by gas.

Benardos Arc Welding.—It is in the manufacture and attachment of flanges, branches, bends, and tee pieces, that the Benardos system of welding by means of the electric arc plays such an important part. This process has now been in constant operation for over five years at Messrs. Lloyd and Lloyd's Coombs Wood Works, near Halesowen, with which the author is connected, where during this period it has been employed chiefly on large steel pipes and connections, suitable for high-pressure steam. The process has been so fully and clearly described from time to time in the various technical and scientific journals, that it is unnecessary to do more than briefly illustrate it here, before showing its special application in connection with the subject of the present paper. The method of working is simple. Ordinary low-tension continuous-current lighting dynamos are used; to the terminals of these a battery of Benardos accumulators is connected, into which the current flows continuously. When the welding circuit is closed, the current flows from the dynamos and accumulators; and large resistances are used when necessary. In this way a large discharge is obtained, equal to about twice the capacity of the dynamos, and the load factor of the apparatus is high. For some purposes it is possible to work without the accumulators; but when this is done the efficiency of the apparatus is not so high, because during part of the working period no current whatever is passing, and the machinery is running light.

As illustrated by the diagram, Fig. 6, Plate 45, the plant is run on the parallel system; and between the terminals of the dynamos or battery as many welding arcs can be connected as may be desired; and every welder is able, independently of the others, to vary his own current to suit the work in hand at the moment. One terminal of the circuit is connected by means of a flexible cable to a carbon pencil in an insulated holder, Figs. 7 to 9, which is held by the workman; the other terminal is connected to the table on which the work lies, or to the work itself. When iron or steel is under treatment, it is

usual to make the carbon the negative pole, and the iron or steel the positive pole; but for other metals the poles are sometimes reversed.

In the appendix is given a summary of the results of experiments made by Messrs. David Kirkaldy and Son for Messrs. Lloyd and Lloyd, to ascertain the tensile strength of electric-welded bars of various brands and sizes; and also a comparison of these with fire-welded bars.

Flanges.—The method usually adopted for welding flanges to steam-pipes is as follows, Figs. 10 to 15, Plate 46. The flange is stamped out under the steam-hammer in such a way that a V shaped groove is left on the inside edge, as shown in Fig. 11, extending about three-fourths through the thickness of the metal. The flange is next shrunk upon the tube, with its flat face outwards or at the end of the tube, and is carefully set in the exact position required, Fig. 12. The welding consists in laying small pieces of steel in the V shaped groove, and welding them in one by one by means of the electric arc, Fig. 12, the welds being freely hammered between each heat. The welder makes a complete circuit of the back of the flange, and fills it up sufficiently to make a fillet of about 1½ inch radius, Fig. 13. In this way the flange is solidly welded to the tube at the back, and about three-fourths of the way through its thickness, Fig. 13; but the front or outer side is not yet welded. The tube is then up-ended, Fig. 14, and the outer side of the flange is welded to the tube, the only difference being that the heat of the arc is used to burn out a cavity all round the junction of the pipe and the flange, until the depth is reached at which the two have already been united; this cavity is then welded up, Fig. 15, in the same way as the back of the flange, thus ensuring that the flange is welded solid to the pipe right through.

Outlets, Branches, and Tee Pieces.—The welding in of outlets and branches into steam-tubes is done by much the same method as already described in the case of the flanges. The outlet, which consists of a piece of ordinary lap-welded tube, is cut off to the required length, and a hole is burnt by the arc in the tube, large

enough for the outlet just to fit into. When fixed in the right position the outlet is welded in, as in the case of the flange, by laying on small pieces of steel about 1 inch long by $\frac{3}{4}$ inch wide and $\frac{1}{4}$ inch thick, and welding them in one by one, continuing the process all round the outlet, until a fillet is formed of about $1\frac{1}{2}$ inch radius, but this varies slightly with the position of the outlet on the tube. A tee piece is made in a precisely similar way, a short piece of tube being welded into a longer piece, Fig. 16, Plate 47; and a cross, Fig. 17, is made by welding two similar short pieces, one on either side of the main tube.

Bends and Expansion Pipes.—These are made by the same method as the outlets and tee pieces. In Fig. 18, Plate 48, is shown a form of expansion bend, of which a number are at work, and are found highly effective.

Length and Size of Arc.—One point in connection with electric-welded work, to which the author would call special attention, is the length and size of the arc which is used in the welding of various kinds of work. With a short arc, the carbon point is brought down too close to the steel; and the result is inferior work, not only from the presence of the carbon, but also because the heat is concentrated upon so small a surface that the strains set up in cooling are considerable. The longer the arc, the softer and more diffused is the heat; and any slight strain which may be set up can be got rid of by careful annealing. A long arc is therefore indispensable to the proper working of the system.

Strength of Electric-welded Flanges.—An 8-inch iron pipe $\frac{1}{4}$ inch thick, with flanges electrically welded on, when tested to destruction at Lloyd's Proving House, Netherton, broke in the body of the pipe at over 88 tons, the welded part remaining intact; and a similar pipe of steel broke in the welded part of the flange at over 101 tons. These tests were tensile only, and were carried out with the view of proving the absolute soundness and consequent strength of the flanges electrically welded on. For this purpose special tackle was made. A blank flange with an eye-bolt attached was

secured to each flange of the pipe, and the chain of the testing machine was connected with the eye-bolts at each end, with the result given above.

Other applications of Arc Welding.—All kinds of work of the above description can be readily and satisfactorily done by this process; but its utility in large works does not stop here. Small flanges can be heated and welded upon tubes by spinning them in a lathe at a high speed, and allowing the arc to play on them, the weld being made by the pressure of two rollers, one inside and the other outside the tube. Defects in steel castings and in finished forgings can be repaired with the greatest ease; and the fact that, when such repaired articles are faced or turned in the lathe, the turnings come away sound and whole, is a proof that the welding has been perfect, and that the metal has not been burnt or rendered brittle by the process.

Reverting to steam-pipes with flanges and outlets electrically welded on, these have been in constant request ever since the Benardos system was introduced into this country some five and a half years ago by Mr. Henry Howard; and the electric welding department at Messrs. Lloyd and Lloyd's Coombs Wood Works has been kept going almost night and day. The principal demand has come from the various electric lighting works, for which the advantage and security were at once recognised of the solid welded flange, and also of the reduction in the number of joints by the outlets being welded to the tube. In many instances also the bend and the tube have been made in one piece, thus further reducing the joints. The City of London electric lighting station at Bankside has been almost entirely fitted with these pipes. They are also adopted at the Metropolitan electric lighting station at Amberley Road, the Kensington and Knightsbridge, the Bristol, and the Nottingham electric lighting stations, and many others. Among users of these pipes and fittings in connection with high-pressure steam-engines may be mentioned Messrs. Pearson and Sons, Blackwall Tunnel Works; Messrs. J. Musgrave and Sons, Bolton; Sir Titus Salt, Bart., Sons, and Co., Saltaire; and many others.

Joints.—In connection with the cognate subject of joints, the author is enabled by the kindness of Mr. Frank Bailey to describe a simple form of joint in use at the City of London and the Metropolitan electric lighting stations, which in conjunction with the solid electrically welded flanges has given excellent results. As shown in Fig. 19, Plate 48, the joint is made simply with a copper ring 1-8th of an inch thick, of which a specimen is exhibited. These rings are cut of the required thickness from a copper cylinder of the necessary size, and are carefully annealed. The great thickness of the solid welded flanges admits of their being screwed tightly together, without any possibility of springing; and an absolutely steam-tight and durable joint is thereby made, which gives no trouble whatever. The joint shown in Fig. 19 is one made between two butt ends of wrought-iron steam-pipe, which have not got flanges welded on them, but only collars welded on or screwed on and brazed; behind the collars are loose wrought-iron flanges, in which the bolt-holes have been drilled to template before fixing the collars on the pipe ends; the loose flanges facilitate adjustment in making the joint.

Bolt holes.—Another great advantage of the solid welded flange is that it obviates any difficulty with the bolt holes. The frequent trouble and annoyance experienced with screwed flanges, from the bolt holes not coming fair opposite each other, are well known; and the objections to flanges riveted on steam pipes are too obvious to need any comment.

Appendix.

In Table 2 (pages 240–1) is given a summary of experiments to ascertain the tensile strength, contraction of area, and extension, of electrically welded bars of Lowmoor iron, Parkgate steel, Farnley iron, and Netherton crown best iron; ten bars were tested of each of the

(*continued on page* 242.)

TABLE 2 (*continued on opposite page*).

Mean Results of Tests of Electric-Welded Bars.

Brand.	Nominal Size.	Fracture through Solid or Weld.	Ultimate Tensile Strength per sq. inch. T	Contraction of Area at Fracture. C	Extension in Ten inches.	Tensile Strength. Ratio of Weld to Solid.
	Inches.		Lbs. Tons.	Per cent.	Per cent.	Per cent.
Lowmoor Iron	$2 \times \frac{3}{16}$	Solid	58,417 = 26·1	42·3	19·5	
		Weld	47,367 = 21·1	17·3	7·3	81·1
	$2 \times \frac{1}{4}$	Solid	55,537 = 24·8	45·7	22·9	
		Weld	48,429 = 21·6	20·9	8·1	87·2
	$2 \times \frac{5}{16}$	Solid	53,237 = 23·8	46·0	24·1	
		Weld	48,890 = 21·8	20·7	9·7	91·8
	$2 \times \frac{3}{8}$	Solid	55,363 = 24·7	41·7	26·7	
		Weld	49,517 = 22·1	16·7	9·0	89·4
	$2 \times \frac{1}{2}$	Solid	47,872 = 21·4	46·9	31·3	
		Weld	46,343 = 20·7	19·2	10·2	96·8
Parkgate Steel	$2 \times \frac{1}{8}$	Solid	67,846 = 30·3	57·1	22·3	
		Weld	49,956 = 22·3	18·4	3·8	73·6
	$2 \times \frac{3}{16}$	Solid	57,268 = 25·6	57·2	25·7	
		Weld	46,482 = 20·8	16·0	4·2	81·2
	$2 \times \frac{1}{4}$	Solid	56,730 = 25·3	57·4	27·0	
		Weld	44,464 = 19·8	17·5	4·4	78·4
	$2 \times \frac{5}{16}$	Solid	54,819 = 24·5	57·1	26·4	
		Weld	46,405 = 20·7	17·1	6·1	84·7
	$2 \times \frac{3}{8}$	Solid	55,932 = 25·0	54·7	26·0	
		Weld	45,044 = 20·1	15·5	6·3	80·5
	$2 \times \frac{1}{2}$	Solid	54,486 = 24·3	61·2	31·5	
		Weld	47,100 = 21·0	15·4	7·3	86·4
Farnley Iron	$2 \times \frac{1}{8}$	Solid	53,918 = 24·1	31·2	17·3	
		Weld	46,281 = 20·7	6·5	4·4	85·8
	$2 \times \frac{3}{16}$	Solid	59,207 = 26·4	37·4	18·1	
		Weld	45,887 = 20·5	8·6	4·4	77·5
	$2 \times \frac{1}{4}$	Solid	52,816 = 23·6	35·7	23·3	
		Weld	48,365 = 21·6	17·6	6·5	91·6
	$2 \times \frac{3}{8}$	Solid	49,005 = 21·9	49·4	27·5	
		Weld	48,231 = 21·5	13·1	6·4	98·4
	$2 \times \frac{1}{2}$	Solid	49,028 = 21·9	44·7	26·7	
		Weld	42,343 = 18·9	10·5	4·6	86·4

(*continued from opposite page*) TABLE 2.

Mean Results of Tests of Electric-Welded Bars.

Brand.	Nominal Size.	Fracture through Solid or Weld.	Ultimate Tensile Strength per sq. inch. T	Contraction of Area at Fracture. C	Extension in Ten inches.	Tensile Strength Ratio of Weld to Solid.
	Inches.		Lbs. Tons.	Per cent.	Per cent.	Per cent.
Netherton Crown Best Iron	$2\times\frac{3}{16}$	Solid	51,892=23·2	23·5	11·2	
		Weld	44,122=19·7	8·6	4·7	85·0
	$2\times\frac{1}{4}$	Solid	48,910=21·8	22·7	10·6	
		Weld	44,995=20·1	10·8	4·5	92·0
	$2\times\frac{5}{16}$	Solid	56,298=25·1	23·7	18·0	
		Weld	40,732=18·2	7·0	2·2	72·4
	$2\times\frac{3}{8}$	Solid	56,292=25·1	24·3	20·9	
		Weld	41,064=18·3	5·8	2·5	72·9
	$2\times\frac{1}{2}$	Solid	53,485=23·9	29·5	23·2	
		Weld	41,539=18·5	5·5	3·4	77·7

TABLE 3.—*Mean Results of Tests of Fire-Welded Bars compared with Electric-Welded.*

Brand and Size. F=Fire-welded. E=Electric-welded.	Ultimate Tensile Strength per sq. in. T	Contraction of Area at Fracture. C	Extension in Ten inches.	Ratio of Weld to Solid.	Figure of merit. T×C
Brand. Inches.	Tons.	Per cent.	Per cent.	Per cent.	
Lowmoor Iron $2\times\frac{3}{16}$ F	20·3	15·2	7·3	77·9	308
Lowmoor Iron $2\times\frac{3}{16}$ E	21·1	17·3	7·3	81·1	365
Lowmoor Iron $2\times\frac{5}{16}$ F	21·5	22·3	11·3	90·7	479
Lowmoor Iron $2\times\frac{5}{16}$ E	21·8	20·7	9·7	91·8	451
Netherton Best Iron $2\times\frac{1}{4}$ F	18·4	10·1	3·4	84·4	185
Netherton Best Iron $2\times\frac{1}{4}$ E	20·1	10·8	4·5	92·0	217
Parkgate Steel $2\times\frac{1}{8}$ F	20·9	9·3	1·9	69·1	194
Parkgate Steel $2\times\frac{1}{8}$ E	22·3	18·4	3·8	73·6	410
Parkgate Steel $2\times\frac{1}{2}$ F	20·4	15·9	8·1	82·3	324
Parkgate Steel $2\times\frac{1}{2}$ E	21·0	15·4	7·3	86·4	323

$$118\cdot5 \text{ per cent.} = \frac{\text{Average of Electric-welded bars} = 1766}{\text{Average of Fire-welded bars} = 1490}$$

five sizes named, and the mean results are here recorded of the ten welded and the ten solid bars of each size. All the welds were scarf, the length of scarf averaging $1\frac{1}{4}$ to $1\frac{1}{2}$ inch. The results obtained from the welds of Lowmoor iron, Parkgate steel, and Farnley iron are satisfactory: the principal features are absence of cinder or impurities from the faces of the scarf, and the maintenance of a fair amount of ductility at the weld, the material not being abnormally affected by the heating. Where the welds have come out low, the appearance of the fracture points either to the metal having not been hot enough, or to the thin edge of the scarf having cooled before the weld was closed by hammering. In the welds of the Netherton iron there is a serious tendency to loss of ductility, the fractures showing crystalline. As however there are some good welds amongst them without these objections, it would appear as if the treatment, as regards the amount of heat, had not been adapted to the nature of the iron. In order to judge of the full merits and capabilities of the electric welding, due regard must be paid to the individual results as well as to the average. The mean results in Table 2 are based upon the whole of the ten welds, as far as the ultimate stress and the ratio of weld to solid are concerned; but as regards the contraction of area and the extension, the results are the mean of the bars which broke through the weld, because necessarily, where the weld did not break, the contraction and the ultimate extension could not be obtained.

In Table 3 (page 241) is given a summary of experiments to ascertain the tensile strength, contraction of area, and extension, of fire-welded bars of different sizes of the foregoing brands, welded by engineers' smiths; and also a comparison with the electrically welded bars. The general average of the electrically heated welds is seen to be $18\frac{1}{2}$ per cent. better in figure of merit than that of the fire-heated welds. The welding of the fire-heated iron bars was well done, the difference being slight compared with the same sizes heated electrically; but turning to the steel, the fire-heated welds are more irregular or uncertain, some being good and others bad.

Discussion.

Mr. MacCarthy exhibited a collection of specimens illustrating the arc-welding processes described in the paper. One was a flange cut in two longitudinally and showing the welding process only partly completed, while another showed it fully completed. A third specimen showed the same thing in a tee piece, which was not quite finished, having been purposely left so in order to show the process of welding the shorter piece of tube into the longer. All the specimens were steel, and all were electrically welded precisely in the manner described in the paper and shown in the diagrams. The importance of the best possible steam-pipes being used had been emphasized since the preparation of the paper had been begun, by another accident in a Brush arc-light station in New York city, which had been reported as follows in "The Engineer" of 17 January 1896, page 59:—"The bursting of an 8-inch cast-iron elbow ruined 3,000 dollars' worth of belting, and put the station out of service for twenty-four hours. Fortunately the station attendants escaped with their lives. The steam-piping of a large central station has come to be one of its most important features, owing to the practice of connecting up boilers and engines in such a manner as to permit any part of the plant to be cut out, and to the attempt to provide duplicate pipe systems to a greater or less extent. It is worth considering whether better results might not be secured by striving to simplify the pipe systems so far as possible, and, instead of duplicating piping, by putting sufficient additional expense into the single line of piping to make it absolutely safe."

Mr. William Schönheyder concluded that, in the welding of outlets, branches, and tee pieces or crosses, according to the process described in the paper, there must be more or less of a sharp corner inside the pipe, wherever the welding had taken place. It must be rather a disadvantage he thought for the steam to have to pass round a sharp corner; and he enquired whether it was possible to avoid that, by welding the junction with large rounded corners such as were usually preferred.

Mr. Druitt Halpin described a pipe joint designed by the late Mr. Willans for high-pressure steam-pipes, which he thought had some advantages over the joint shown in Fig. 19, Plate 48. The pipe ends were screwed, and had heavy flanges screwed upon them a short distance behind the end of each pipe, Fig. 20, Plate 49; and the whole of the objection referred to in page 239 of the paper, regarding the bolt holes, was got over, because all the flanges were here free to be rotated till the holes came fair opposite each other; or if they stuck so fast that they would not come off, they were simply turned off. The beauty of the joint was that it could be made to take apart and put together again as often as was desired, and it was always absolutely steam-tight. The copper ring R was here diamond-shaped in section; and the joint was surrounded outside by a cast-iron thimble T, for convenience in getting the pipe ends together. The thimble was slipped back for getting the ring into its place, and was then pulled forwards again over the joint, which was tightened up by a sufficient number of bolts through the flanges. All the faces of the pipe ends were turned quite flat. Having himself used many hundreds of joints made in that way, he had never had one of them leak.

Mr. S. Earnshaw Howell, having had a good deal of experience during a considerable period in the welding of tubes, thought that the electric welding described in the paper should not be called welding at all; it should rather be called electric soldering, because the metal which was said to be welded was not really welded, but was fused. There seemed to him to be great liability of the steel at the root of the flange in the immediate neighbourhood of the weld being reduced in quality by the fusion, and becoming more brittle than the remaining part of the tube. In 1892, with a view to testing the welding of steel tubes by rolls, he had taken a 4 ft. 8 ins. length of tube so welded, and had cut it into rings two inches long, of which there were twenty-eight. The first ring was then cut open along the weld, and the next ring was cut open opposite the weld; and similarly for the rest of the fourteen pairs forming the whole length of the tube. The rings so cut were then opened out to form

flat bars, which were tested for tensile strength in the usual way. Of the fourteen bars which had the weld in the middle of their length, six did not break in the weld at all. The whole tensile strength of the fourteen solid bars added together was 317·94 tons per square inch, giving an average of 22·71 tons. The total tensile strength of the fourteen welded bars was 315·95 tons per square inch, giving an average strain on the welds of 22·57 tons, which showed that they were nearly as strong as the solid bars. Instead of a long datum length of ten inches, such as had been taken in the tables appended to the paper, he had taken a datum length of only three inches for measuring the percentages of elongation, which in the fourteen solid bars amounted to a total of 529·80, or an average of 37·84 per cent. extension. The percentages of elongation in the fourteen welded bars amounted to a total of 424·89, giving an average of 30·34 per cent. extension. So that, although the elongation of some of the welds was not really low, it was not nearly so good as that of the solid; but for all practical purposes he thought it was sufficiently near. The only objection in his opinion to roll-welded tubes was that in drawing the tube over the mandril there was the danger of getting one side thinner than the rest. He therefore preferred to rely rather on gas welding, which seemed to have been used generally for the purpose of the longitudinal welding of tubes. Since receiving an advance copy of the paper he had rapidly made a few tests similar to those recorded in Table 2, and with the same quality of steel from Parkgate. In that table it was seen that the electric-welded bars of $2 \times \frac{1}{8}$ inch section gave a tensile strength of 30·3 tons per square inch in the solid, and in the weld 22·3 tons. Gas-welded bars of the same section gave in his own tests 26·48 tons in the solid, and 24·44 in the weld: which was much closer than in the case of electric welding. Again the elongation in the electric-welded bars fell from 22·3 per cent. in the solid to only 3·8 per cent. in the electric-welded bars. With gas welding the elongation was 18 per cent. in the solid and in the welded bar 21·5 per cent., being even greater in the welded bar than in the solid. The particular gas-welded bar which showed this high elongation did not break in the weld at all, but broke in the solid.

(Mr. S. Earnshaw Howell.)

In the gas-welded bars of $2 \times \frac{3}{16}$ inch section similar results were obtained in comparison with the electric-welded Parkgate bars of that section in Table 2. The conclusion he had come to therefore from these and other observations he had made was that electric welding was not so good as gas welding or roll welding. The tendency of electric welding was to make the material short. It might have a high or a moderately high tensile strength; but it might also have a sudden fracture, instead of the large reduction of area and the great elongation which characterised gas-welded or roll-welded tubes. The great advantage of electric welding seemed to him to be for welding flanges on pipes, whereby a solid flange was obtained. Another method which he had adopted with the same object consisted in forging out of the solid flange a piece of tube several inches in length, as shown in Fig. 21, Plate 49, which could then be welded upon the end of a long tube by means of an annular weld, whereby an absolutely solid flange was obtained on the tube. It had not been subjected to what he considered was nothing else than burning, because by the electric arc the steel was fused, and there was not sufficient work put upon it afterwards to bring it back to its original quality; consequently the root of the flange was in his opinion weaker than the rest of it. Many of the specimens now shown were certainly good work, but some of them seemed to him to be not at all essential. Unions and tee pieces for instance could be made of crucible cast-steel of as good a quality as the steel used for the pipes themselves, and could be made quite reliable and at much less cost; he therefore did not see the great advantage of electric welding for this class of work. The great advantage of electric welding was that it enabled branches and other pieces to be welded on steel pipes, which it would be extremely difficult to do with gas, because the work could not be easily got at. If it could be got at readily, the weld made by gas would be just as good as the longitudinal gas weld forming the seam of the tube. This at any rate was his own experience.

With regard to corrosion, of course all steel would corrode if acids came in contact with it; the endeavour should therefore be to keep the steel clean. Another point which had been much ignored

in the construction of steel tubes and steam-pipes was the need of paying due regard to chemical analysis. Steel of one analysis he believed was not nearly so liable to corrosion as of another; and the proper analysis was a matter of practical experience in the manufacture of steel tubes.

Mr. James Platt, Member of Council, said steel pipes had become so generally used that it was useful to know how they were made, and the details of the joints and other particulars. If the electric welding could be relied upon to be perfectly sound, there could be no doubt that it was a capital job. There was certainly not so much hesitation in regard to the electric welding or soldering of the flange on the pipe as there was in respect of welding the longitudinal seam, which he gathered from the paper was not now done electrically, but by gas. As to the soundness of the longitudinal seam in wrought-iron and steel welded pipes, it was generally asserted that the welds were sound; and in some tests it had been reported that the weld had been found to be sounder than the body of the pipe. Nevertheless there was still a good deal of doubt about this; and the Admiralty, as explained in the paper, required a cover strip to be riveted on along the line of the weld. The question therefore suggested itself, what was the need of welding at all, when a perfectly sound seamless pipe could be made out of a solid ingot. Seamless pipes were now being made by the Projectile Co. in London up to 12 inches diameter, 12 feet long, and $\frac{1}{4}$ inch thick, cold drawn from a solid ingot, and perfect in every respect; and they could be obtained, sound and good, of any size up to that diameter. The solid steel bloom first had a hole driven in it with a punch, and was then drawn on a mandril to a certain length, after which it was further drawn down through a die, not through rolls. The cost of course was considerable; but if a good job was wanted, it was worth paying for. These solid-drawn tubes were being largely used by the Admiralty; and he thought the mode of manufacture made a much safer job than could be obtained by any welding of the longitudinal seam, notwithstanding all the care well known to be taken by the best makers of welded tubes for ensuring

(Mr. James Platt.)
a sound weld. Engineers he considered ought to foster the plan of making weldless pipes, so long as there remained any vestige of doubt in regard to soundness of welding.

Reference was made in the paper (page 238) to the application of arc welding for faking up steel castings or finished forgings; and he should be glad if the users of the arc could be instructed how to make up defects by that means in such a way that the work would turn perfectly well. In turning some large steel cylinders he had discovered to his cost that they had been faked up by the electric arc; for instead of taking two days to turn out the bore, they had taken two weeks. The pieces burnt in were harder than anything he had met with before in the shape of steel that was intended to be worked; in fact he had had to lubricate with petroleum, and get the hardest steel tools he could for turning out the cylinders. Of course it was highly convenient for steel founders to be able to make up defects which might otherwise spoil costly castings; and if this could be done so that the castings could be readily machined afterwards, the engineers using the castings would be glad indeed. He hoped therefore that the author would instruct the users of the arc how to do the work so that it could still be dealt with afterwards by the usual engineering tools without difficulty. The samples exhibited of outlets, branches, and tee pieces, were all nicely finished; and although they did not follow the same curve inside that they did outside, they were externally good looking. For his own part he should prefer a steel casting.

With regard to the flanges described in the paper (page 236). some thirty years ago he had used a considerable quantity of wrought-iron pipes on which the flanges had to be fixed; and he had employed a good stout wrought-iron flange, bored out a little conically, as shown in Fig. 22, Plate 49, and shrunk on the pipe, with the end of the pipe left projecting a little beyond the flange. The pipe end being then riveted over made a perfect joint and a perfect flange; and he had experienced no trouble at all with the flanges so fixed, which made a perfectly tight joint for the pipes. The flange was not welded at all, but only riveted. If the arc welding had been applied to the face of the flange, it would have

made it appear a more finished job. Filling in at the back he considered was only ornamental, and in respect of strength could be dispensed with when the pipe end was riveted over; still it made a nice finish to the back of the flange.

In the pipe joint described in the paper and shown in Fig. 19, Plate 48, which he considered was a good joint, he suggested that it would be preferable if the copper ring were kept flush with the inside of the pipe, and of smaller diameter outside. It would then protect the thread more completely from the action of the steam; and the steam pressure would not be acting upon the ends of the pipe to force them apart. There would be no objection to using a copper ring of smaller external diameter than the collars on the pipe ends; and he thought it would make a good joint.

Mr. Mark Robinson mentioned that, altogether independently of the paper, it happened that some experiments had been made a few days ago at the works of his firm at Thames Ditton, by Mr. Eaton-Shore, the works manager, with some lap-welded steel tubes of 4 inches diameter, supplied by Messrs. Lloyd and Lloyd. The experiments were for the purpose of comparison with weldless steel tubes. The tubes were first flattened in various ways, and the welded tubes came out much the best; the weldless tubes showed certain longitudinal striæ which were not found at all in the lap-welded tubes. Next they were tested by drifting, until they were burst open after considerable enlargement. Here again the lap-welded tubes came out best: they enlarged most before they split, and the split did not extend so far; moreover it was not along the weld that they split, but through the solid. A piece about 5 inches long was then cut from the uninjured portion, and doubled up endwise, first by blows from a heavy sledge, and then by hydraulic pressure. Under this treatment the lap-welded tube folded up like an accordion, in three folds, showing no split or injury whatever; it was impossible to see where the weld was. Ultimately, when it was still further compressed, a small split opened, as might be seen in Fig. 23, Plate 50. The weldless tube shut up in less regular folds, and split much earlier and somewhat badly, as shown

(Mr. Mark Robinson.)

in Fig. 24. In both cases the tubes experimented upon were taken indiscriminately out of a large lot without selection. The experiments would be carried further. The purpose for which the tubes were required was not steam piping, but one for which it was important to know whether the lap-welded tubes could be trusted as thoroughly as the weldless tubes.

The design of joint referred to by Mr. Halpin (page 244) as introduced by Mr. Willans, Fig. 20, Plate 49—with which he thought Mr. Halpin himself had had more to do than he had represented—had been developed from a suggestion to use sharp-edged steel rings of diamond section, as in the joints of Perkins hot-water pipes. Mr. Willans preferred to use copper rings; and the first trials resulted in the diamond section being given up in favour of a thin flat ring, on the recommendation of Captain Sankey. The pipe joint used by their firm for several years past was substantially that shown in Fig. 19, Plate 48, the main difference being that the copper ring was much narrower from inside to outside, because their experience was that a ring as wide as that shown in Fig. 19 did not make a satisfactory joint; the ring might also be very thin. The collars moreover were welded on the pipe ends, instead of screwed on as in Fig. 19, because experience had shown the unreliability of screwing for fixing the collars on. In a large electric-lighting installation which they had fitted up in London some years ago, where the pipes were of considerable size, the collars had at first been screwed on; but on drawing them together with sufficient pressure to make a tight joint, it was found that the pipes compressed sufficiently to allow the threads to ride over each other. Even if this difficulty had been got over, the effects of expansion and contraction alone would have led to slackness in the flanges, with probable danger of slipping.

Mr. C. Frewen Jenkin had made a large number of tests of electrically welded samples when working at Crewe in 1890 with the Thomson welder, and his impression was that they had given better results than those shown in Table 2. In Sir Frederick Bramwell's paper on that mode of welding, read before the Institution of Civil

Engineers in 1890 (vol. cii, page 33), tests were given of electrically welded samples of the same brand of iron—Farnley iron; and the average ultimate breaking stress of those which broke in the weld was 21·5 tons per square inch, or 4½ per cent. higher than the 20·6 tons average of the results given in Table 2 of the present paper; while the extension, instead of being only an average of 5·3 per cent., was 22 per cent., showing that with the Thomson welding the extension was much better than that obtained by the Benardos arc welding. These figures however were not strictly comparable, since in the latter case the samples which broke in the weld were excluded, and in the former case those which broke in the solid were excluded.

Mr. E. Tremlett Carter pointed out that an electrical action took place in electrical welding, which distinguished it from mere heating, and was sufficiently clear to render it certain that electric welding was not merely a process of soldering or of fusion of the metal. The action was in reality the electrolytic migration of the molecules of the one piece of metal into the other piece, constituting a sort of molecular dove-tailing. The electric current seemed to carry the particles of the semi-melted metal of one of the welding surfaces into the metal of the other surface, so that the two became interlocked, not merely melted and stuck together. This was rendered more particularly evident on trying, for example, to weld steel to copper, which he apprehended it would be very difficult to do by the ordinary process. In welding electrically a high-carbon steel to copper by a butt weld, it was found that the copper was carried some appreciable distance into the mass of the steel, and the steel was similarly carried beyond the actual butt into the copper; the two metals were not fused together, but there was an electrolytic process, a convection of each metal into the other, which gave a much better, stronger, and more uniform joint. Altogether he thought it removed from the process of electric welding the stigma of producing merely a superficial cohesion or stickiness due to the metal having been merely fused over the surface.

With regard to the relative cost of electric and ordinary welding, he believed that in America, where both the Benardos and the

(Mr. E. Tremlett Carter.)

Thomson process had been used largely for all kinds of metal welding and forging, the cost of electric welding had always worked out much cheaper than that of the ordinary welding with fire-heating; but in this country he was not sure whether the electric welding was cheaper. In one or two instances he knew it had proved to be so; but in the use of either of these electric processes in this country there had been more reticence about the cost. He should therefore like to learn the cost of the electrical energy as compared with the cost of the furnace, whether gas or coal was employed for obtaining the welding heat; and also the actual saving in time effected by using the electrical process. The great saving in time over other processes was one of the distinctive features in electrical welding.

The President enquired what lengths of pipes were made by the processes described in the paper. It appeared to him that by the aid of the arc-welding process steel steam-pipes might be made of great length, with decided advantage for use on board ships.

Mr. MacCarthy said it would be observed, on handling the specimens exhibited, that there was a somewhat sharp corner left inside the outlets, branches, tee pieces, and crosses, at the welded joints (page 243). It had not been found practicable to make these joints rounded inside the pipe to the same radius as on the outside. This however was a matter of not so much importance in the case of steam, for which these outlets were specially made, as it would be for a dense fluid such as water or oil, where the avoidance of friction was a paramount consideration. Moreover the considerable increase in the thickness of metal, which resulted from the fillet formed round the outside of the joint, added strength to the part where it was most needed.

The joint described by Mr. Halpin and Mr. Robinson, Fig. 20, Plate 49, he had no doubt was a good one. In preparing the paper it had originally been his intention to go into the question of joints generally; but he had found that almost every engineer had a favourite joint of his own, and he had therefore contented himself

with showing the joint used by Mr. Frank Bailey, which had been found perfectly satisfactory.

That electric welding was not welding, but only soldering or fusing, was an assertion which had been made whenever electric welding had been advocated; but whatever it might be called, he was prepared to show that it was perfectly sound. As for its rendering steel short, the tests made and the long experience of its use clearly showed that this was not the case.

The interesting tests made by Mr. Howell with a roll-welded steel tube cut into short lengths (page 214) were highly satisfactory, as showing that the welded part of the tube was nearly as strong as the solid part.

In reference to corrosion (page 246), a pipe made of iron, steel, copper, or any other metal, would necessarily be affected by acid; but in the ordinary use of steel steam-pipes, judging from his own experience and from the fact that he had not heard of any complaint upon this score, he should say that there was no corrosion.

The solid-drawn pipes of large diameter, up to 12 inches, mentioned by Mr. Platt (page 247), he was aware were being made by the Projectile Co.; but the cost of pipes of this size, made by such a process, must necessarily be so great, that their use as steam pipes had certainly not occurred to him. The Mannesmann method of making seamless pipes he was also acquainted with; but here again arose the question of cost. However excellent such pipes might be, and leaving price out of consideration, there still remained the question of the electrically welded flanges and outlets, which the paper was mainly intended to illustrate.

He was sorry to hear that Mr. Platt had experienced so much difficulty in boring out some steel cylinders which had been repaired by the electric arc (page 248); and the paragraph in page 237 on length and size of arc should be specially emphasized, in order to guard against the risk of a careless or incompetent workman injuring the metal by the use of too short an arc.

The very interesting particulars given by Mr. Mark Robinson (page 249), respecting the tests comparing 4-inch lap-welded tubes

(Mr. MacCarthy.)

with weldless tubes, he had not heard of before; and naturally he was exceedingly pleased to learn the result.

With regard to screwing being unreliable for collars and flanges on the ends of steel steam-pipes, it was not his intention to disparage screwed joints, of which there were a number among the specimens here exhibited; but in connection with modern high steam-pressures he wished to describe what he believed to be the very best, and that was electrically welded flanges. The screwed joints were good when properly made, but he believed the solid welded flanges were much better and safer, at all events for large steam-pipes; and he was glad to find this conclusion borne out by Mr. Robinson's experience (page 250).

With regard to the cost of welding by the Benardos process as compared with non-electrical methods (page 252), he was sorry he was not in a position to give any information; and as to the actual saving in time, effected by using the electric process, this of course depended largely upon the particular class of work operated upon, so that it was impossible to give any precise answer to the question.

In reply to the President's enquiry (page 252), the pipes of large diameters were made by the processes described in the paper in any lengths up to 14 or 15 feet.

The President was sure the members would all accord a hearty vote of thanks to Mr. MacCarthy for his useful paper. The question of having reliable steam-pipes was highly important to engineers, especially for pipes on board ship.

MEMOIRS.

Alfred Crawhall Chapman was born on 18th November 1859, at Hylton Grange, near Sunderland, being the fifth son of the late Mr. Thomas Edward Chapman. After being educated at Rugby School and going through the technical course at the Durham College of Science, Newcastle-on-Tyne, he was articled in 1878 to Mr. John Daglish, Silksworth Colliery, near Sunderland. In 1883 he became a certificated mining engineer, and held appointments at Kimblesworth near Durham, Houghton Main near Barnsley, Cwmaman near Aberdare, Whitburn near Sunderland, and other collieries. In 1884 he abandoned colliery work, and became for two years resident engineer to the River Wear Commissioners on the Roker new pier works, Sunderland, under Mr. H. H. Wake. After a short period spent in London with his brother, Mr. J. Crawhall Chapman, he commenced practice on his own account in 1887 as a consulting, mining, and civil engineer and patent agent, at St. Nicholas Buildings, Newcastle-on-Tyne. He had been considerably out of health for over two years prior to his death, which took place in Durham from pneumonia and typhoid fever, on 3rd September 1896, in his thirty-seventh year. He became a Member of this Institution in 1887, and was also a Member of the North of England Institution of Mining and Mechanical Engineers.

James Cleminson was born in Leeds on 11th October 1840. He was the eldest son of Mr. John Cleminson, locomotive superintendent of the Iquique or original Nitrate Railway, who was also a naval engineer and had fought in the Baltic and under Garibaldi. He was educated at Genoa and Marseilles, and was apprenticed in 1857 to Mr. George England, Hatcham Iron Works, New Cross; and in 1861 was employed as chief draughtsman to the Somerset and Dorset Railway, where his aptitude in designing

rolling stock was speedily recognised. In 1864 he went to London, and became manager to Mr. Robert F. Fairlie, with whom he was intimately associated in designing and bringing out the Fairlie locomotive. From 1865 to 1868 he was chief of the drawing department and technical adviser at the 'Isca Foundry, Newport, Monmouthshire; and on returning to London occupied important positions in connection with the firm of Messrs. Clark, Punchard and Co. In 1874 he commenced business on his own account as civil and consulting engineer; and amongst the many projects with which he was identified were the Buenos Aires and Pacific Railway, of which he was the originator, the Bahia Blanca and North Western, the Villa Maria and Rufino, the Bahia and San Francisco, and the North Wales Narrow-Gauge Railway. He was also consulting engineer to the Imperial Railway of North China, the only railway in China, in which capacity he was well known to Li Hung Chang, and was created a mandarin in recognition of his services. He also received decorations from other countries in appreciation of his railway enterprise. He was the inventor of the flexible wheel-base system of rolling stock known by his name, and used extensively throughout the world. Besides possessing a wide engineering knowledge, he devoted much time to studying the chemical composition of steel. After suffering from a painful malady for several years, his death took place at his residence in London on 15th November 1896, at the age of fifty-six. He became a Member of this Institution in 1871; and was also a Member of the Institution of Civil Engineers, and a Fellow of the Royal Geographical Society.

John William Gray was born on 1st October 1828 at Montrose, where his father carried on business as a general merchant, ship-owner, and flax spinner. He received his early education in his native town, and then at Dr. Cowen's school at Bishop Wearmouth. During his boyhood he took great interest in the flax-spinning mill, which his father started at Balbirnie, near Montrose, and at which he learnt to turn both wood and iron in the lathe, and to understand the working of the machinery. This inclination of his mind led to his being articled to Mr. John Murray, engineer to the River

Wear Commissioners. Improvements of the river and harbour were then in progress, and he was employed on this work and on the preparation of marine surveys for the proposed south docks at Sunderland. After a pupilage of four years he went to London, and was engaged by Mr. W. C. Mylne to assist in the work of the New River Company. There he remained six years, during which time he took an active part in the New River work, and in the private business of his employer, including the building of a reservoir at Limerick, and the re-arrangement of the entire water supply for that city. He was also entrusted with the gauging of the streams in Lancashire, and with arranging the compensations to be paid to millowners in respect of the impounding by the new reservoirs of the Liverpool Corporation at Rivington Pike. He was next associated with Mr. Charles Greaves in carrying out a number of new works for the East London Water Company; after which he returned to Mr. Mylne, for whom he prepared plans for shortening the New River and for re-arranging the system of supply in that district. In 1860 he was again engaged for a short time to assist Mr. Greaves in connection with the East London Water Works. Soon afterwards he started in business for himself, and among various works in which he was engaged were the erection of the first rifle butts at Wimbledon, and a report on proposed harbour works on the banks of the Dee at Holywell. He was also engaged in reporting on a water scheme and tramways for Odessa. In 1866 he was appointed engineer to the Birmingham Water Works. At that time the supply of water to the city was inadequate, and his first work was to carry out various extensions. In 1876 the water works were taken over by the Birmingham Corporation, in whose service he remained as waterworks engineer. The continued growth of the city rendered the question of further sources of water supply one of grave anxiety; and he strongly supported the scheme for going to the Elan and Claerwen district, which was ultimately decided upon. In July 1894 in consequence of failing health he retired after twenty-nine years' connection with the water works, though he continued in their service as consulting engineer. His death took place from peritonitis at his residence at Leamington,

on 14th August 1896, in his sixty-eighth year. He became a Member of this Institution in 1876.

THOMAS HENDERSON was born on 22nd July 1843 at Linlithgow, Scotland. In 1860 he commenced serving an apprenticeship with Messrs. David McDowall, Dublin, and upon its completion went to Messrs. Courtney, Stephens and Co., Dublin, for a short time, and then to Messrs. Easton, Amos, and Anderson, Erith, for about two years. In 1867 he was engaged with Messrs. Walpole, Webb, and Bewley, Dublin, for a short time; and in 1868 he became associated in Liverpool with the late Mr. Dillwyn Smith in the designing and construction of mechanical stokers and furnaces for steam boilers. Afterwards he devoted his whole time and attention to designing and manufacturing mechanical stokers, self-cleaning furnace-bars, air-circulating furnace-fronts, and appliances for the economical use of fuel and for the abatement of the smoke nuisance. His automatic self-cleaning furnaces are extensively used in the boilers of steamships with highly satisfactory results; and he had recently designed an automatic stoker for feeding boilers in saw-mills with sawdust and chippings from wood-working machinery, which has proved most efficient and a great benefit to saw-mill proprietors. His death took place at Southport after a brief illness, on 26th June 1896, in his fifty-third year. He became a Member of this Institution in 1891.

THOMAS GEORGE MARTIN was born in Copenhagen on 8th September 1849, being the youngest son of Mr. John Martin of Aberdeen, who had gone out to Denmark as chief engineer of a steamer employed in the passenger trade to the Baltic ports, but returned to Glasgow in 1852. There he attended school until nine years of age, when he was sent to Gordon's College, Aberdeen, where he remained for five years. He was then apprenticed for five years at the London and Glasgow Engineering Works, Govan, Glasgow, where he afterwards worked for some time as journeyman. After being employed for a short time in Liverpool by Messrs. Fawcett, Preston and Co., Phoenix Foundry, he went to sea for

several years in steamers trading to the Mediterranean, India, and Brazil. In 1872 he became assistant to Mr. George Hepburn, consulting engineer and naval architect in Liverpool, with whom he remained until 1881. In that year he became superintendent engineer for Messrs. John Glynn and Son, Liverpool; and in 1887 entered into partnership with his two brothers-in-law in the firm of Messrs. James McGowan and Co., Wapping Wall, London, engineers and boiler makers. On their death shortly afterwards he carried on the business by himself until the time of his death, which took place on 20th January 1896, at the age of forty-six. He became a Member of this Institution in 1892.

John Thomas North was born in Leeds on 30th January 1842. He was educated at a local school, and at an early age was apprenticed to a machine manufacturer. After serving his time, he obtained a situation as journeyman at the steam-plough works of Messrs. John Fowler and Co., Leeds, by whom in 1869 he was sent out to Peru to superintend the erection and working of machinery. Remaining in South America, he undertook the distilling of sea-water for domestic purposes at a place on the coast north of Valparaiso, where rain never falls; and patching up an old iron steamer that had been wrecked on a reef, he converted her into a floating water-tank. The venture was a financial success, enabling him to purchase a quantity of land in the province of Tarapaca, where he found vast deposits of nitrate of soda, and was quick to realise their great commercial value; the transference of Tarapaca to Chili in 1878 gave a further impetus to the trade, which flourished increasingly as the value of the fertiliser became recognised in Europe. Other enterprises also succeeded, notably the working of the large guano deposits. Having been in South America for about thirteen years, he returned to England in 1882, and established numerous undertakings connected with the nitrate and other industries. In 1889 he presented Kirkstall Abbey and grounds to his native town. He became honorary colonel of the Tower Hamlets Volunteer engineers. His death took place suddenly at his office in London, from failure of the heart, on 5th May 1896, at the age of fifty-four. He became a Member of this Institution in 1882.

William Shapton was born at Bridgwater on 6th June 1845, and was educated near Liverpool. After serving an apprenticeship of five years from 1861 to 1866 in the outdoor department at Liverpool of Messrs. Sir W. G. Armstrong and Co., he became a draughtsman in the Liverpool office of the same firm until 1874, when he was appointed outdoor manager and agent there. After remaining a year in this position he was transferred to London as outdoor and engineering manager, having also the superintendence of the erection of work in the home counties and South Wales. Owing to other changes, the supervision of all outdoor and agency work was shortly afterwards controlled from the London office, with himself as its engineering head, a position which he held until his death. He gave much attention to the question of shipment of coal with the least possible amount of breakage, and introduced several devices for this purpose. He contributed a paper to the Liverpool Meeting of this Institution on grain warehousing machinery at the Alexandra Dock, Liverpool (Proceedings 1891, page 372). For some years his health had been declining, and his death took place in London on 20th August 1896, at the age of fifty-one. He became a Member of this Institution in 1881.

John Leonard Vaizey was born at Halstead, Essex, on 2nd August 1871, and was educated at Harrow School. In February 1891 he became a pupil of Mr. James Holden at the Stratford locomotive works of the Great Eastern Railway; and in February 1894 was placed on the staff of the principal drawing office. In September 1895 he was appointed assistant to the locomotive superintendent of the Norwich district. Whilst engaged in his duties on 29th August 1896, he was caught between the buffers of some wagons which were being shunted in the Norwich yard, and died in a few hours from his injuries, at the age of twenty-five. He became a Graduate of this Institution in 1891.

INDEX.

1896.

Parts 1–2.

Fig. 1. *Back view of Naval Range-Finder.*
(*Eye side.*)

Fig. 2. *Front view of Naval Range-Finder.*
(Window side.)

RANGE-FINDERS.

Internal Frame of Naval Range-Finder.

Fig. 3. *Back view.* (*Eye side.*)

Fig. 4. *Front view.* (*Window side.*)

RANGE – FINDERS.

Internal Frame of Naval Range-Finder.

Fig. 5. *Plan.*

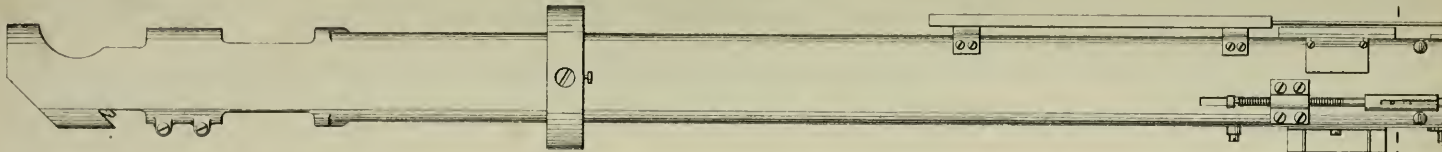


Fig. 6. *Back Elevation (Eye side).*

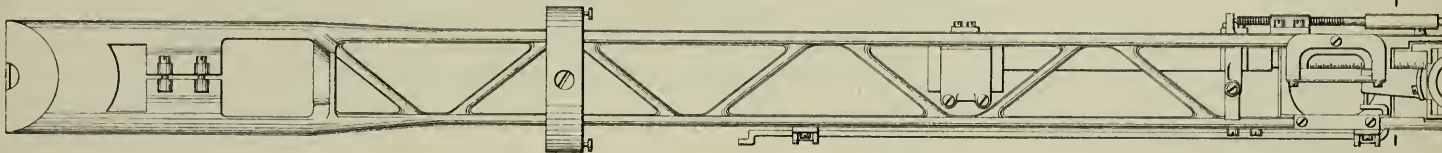
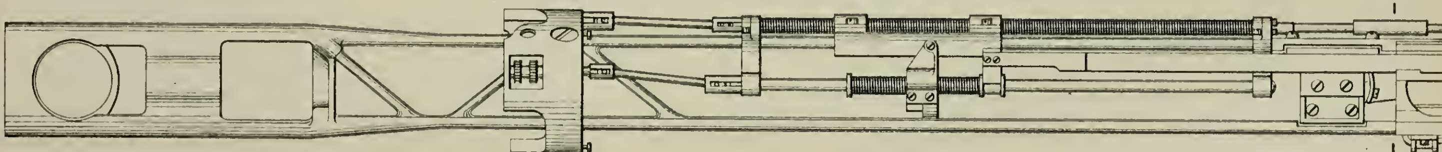
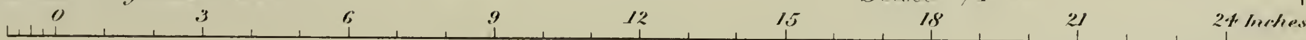


Fig. 7. *Front Elevation (Window side).*



Scale 1/4th



See Continuation in Plate 5.

RANGE - FINDERS.

Internal Frame of Naval Range-Finder.

Fig. 5. *Plan.*

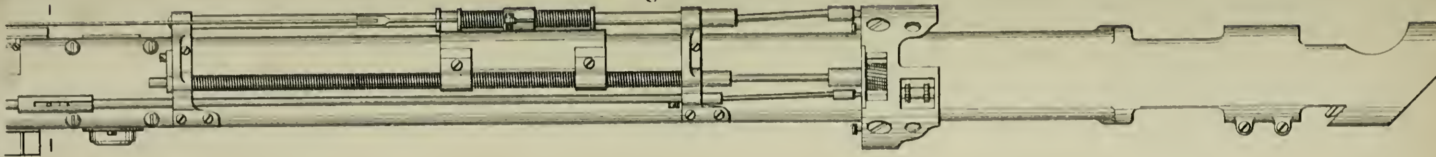


Fig. 6. *Back Elevation (Eye side).*

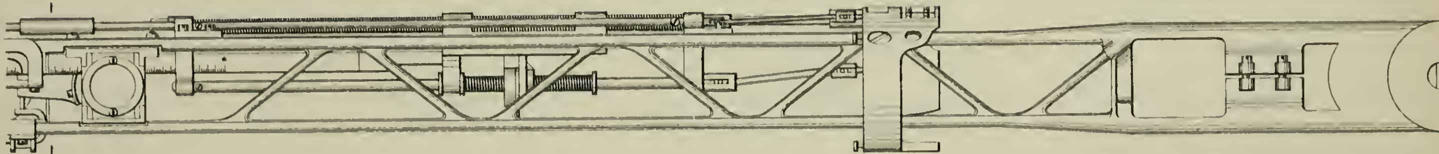
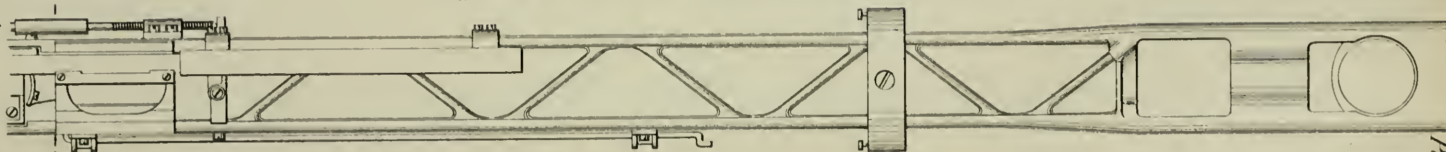


Fig. 7. *Front Elevation (Window side).*



See Continuation in Plate 4.

Scale 1/4th

0 3 6 9 12 15 18 21 24 Inches

Plate 5.

Single - Observer Range - Finder.

Fig. 8.

General Arrangement.

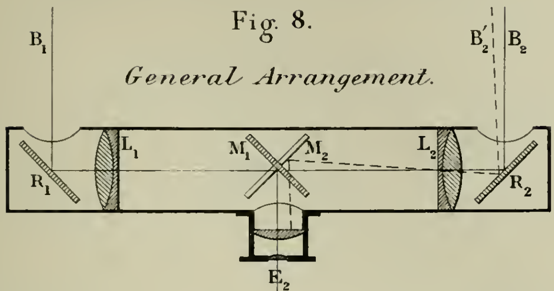


Fig. 9.

Azimuthal Motion.

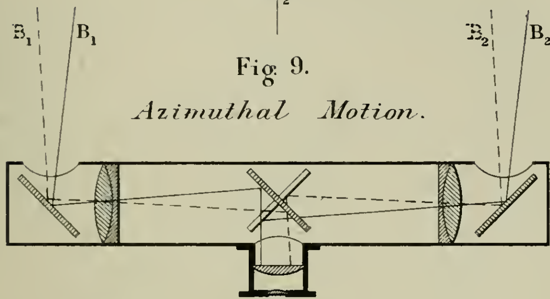
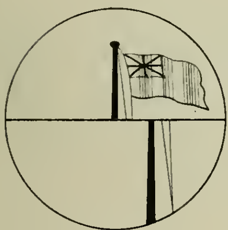


Fig. 10.



Right - eye Field.

Fig. 11.

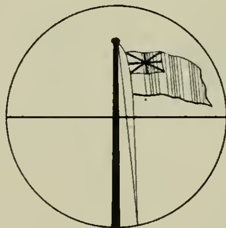


Fig. 12.

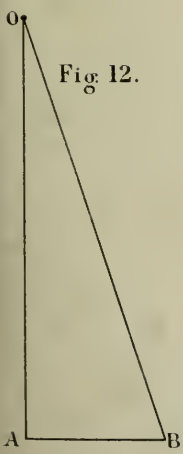


Fig. 13.

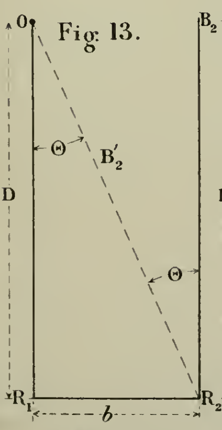


Fig. 14.

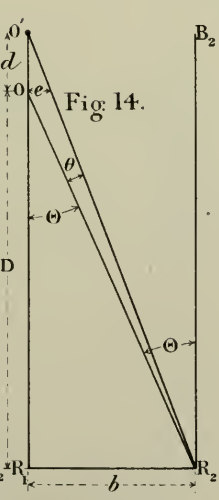


Fig. 15.

Fig. 16.

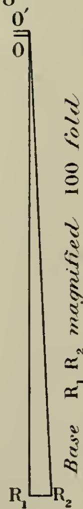


Fig. 17. *Adie, 1860.*

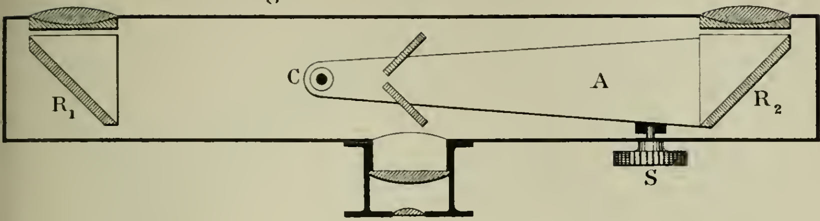


Fig. 18. *Christie, 1886.*

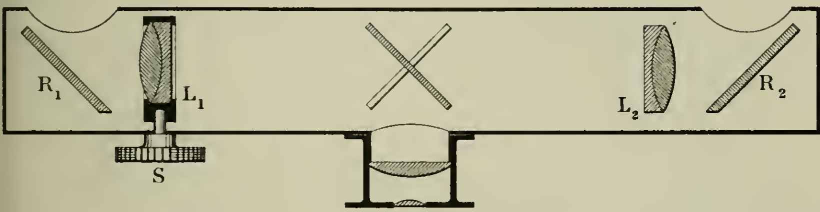


Fig. 19. *Barr and Stroud, 1888.*

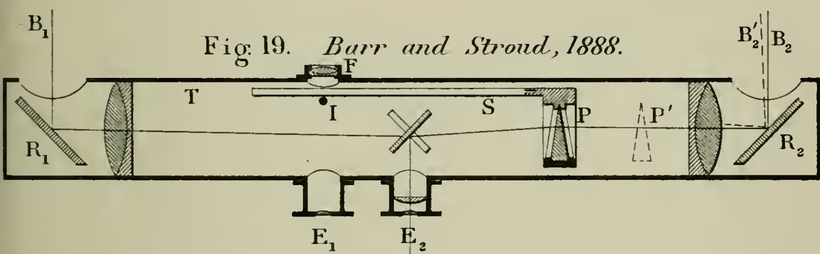


Fig. 20.

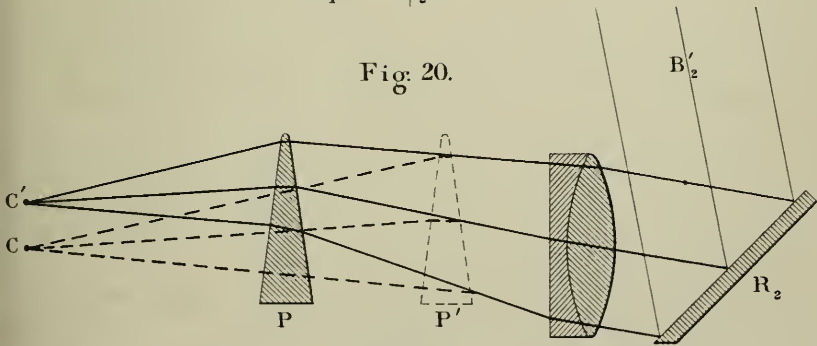
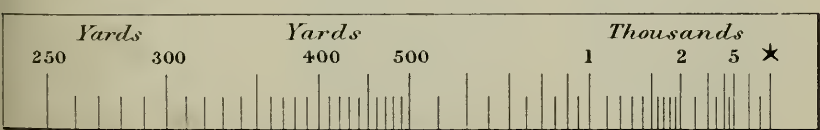


Fig. 21. *Scale.*



Left Eye-piece, Finder, Scale, and Lamp.

Fig. 22.

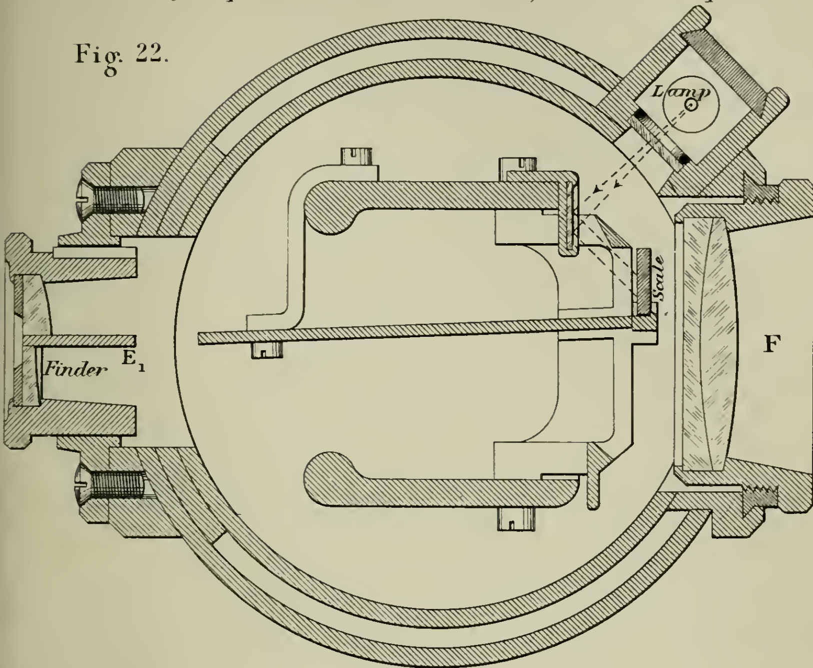


Fig. 23. *Left-eye Field.*

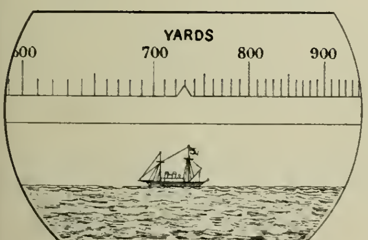
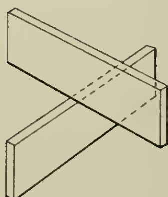


Fig. 24. *Mirrors.*



Astigmatised images.

Fig. 25. *Overlapping images.*

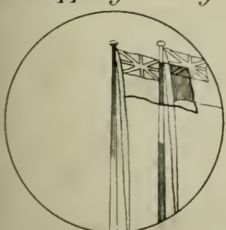


Fig. 26. *A Light.*

Fig. 27. *Search-Light Effect.*

Eye-piece Prism Combination.

Fig: 28. *Plan.*

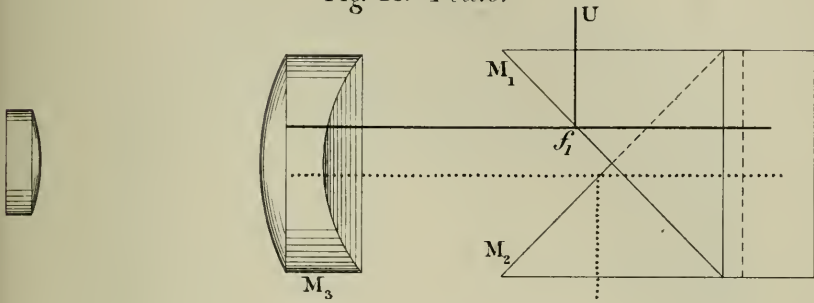


Fig: 29. *Elevation.*

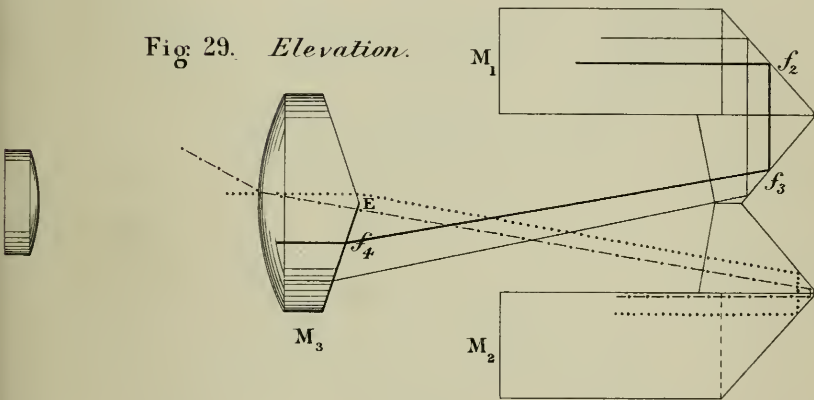


Fig: 30. *Arrangement of Right Eye-piece and Astigmatiser.*

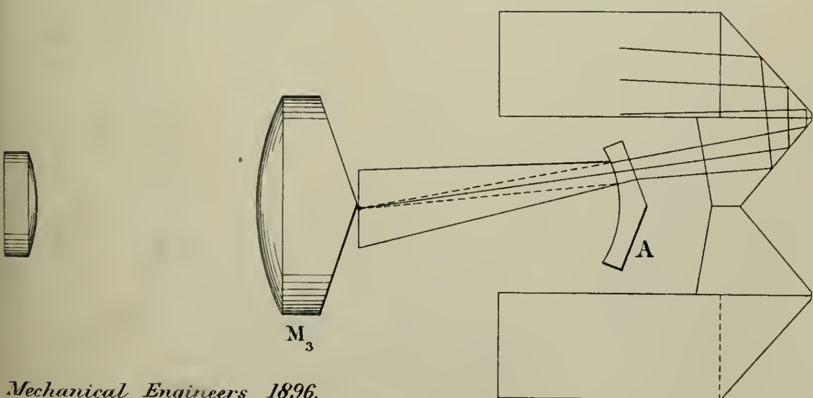


Fig: 31. *Left-hand Support.*

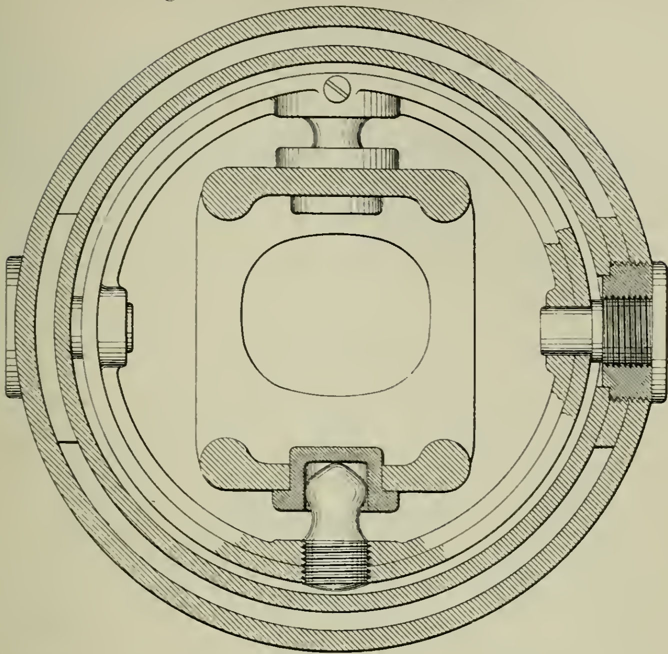


Fig: 32. *Right-hand Support.*

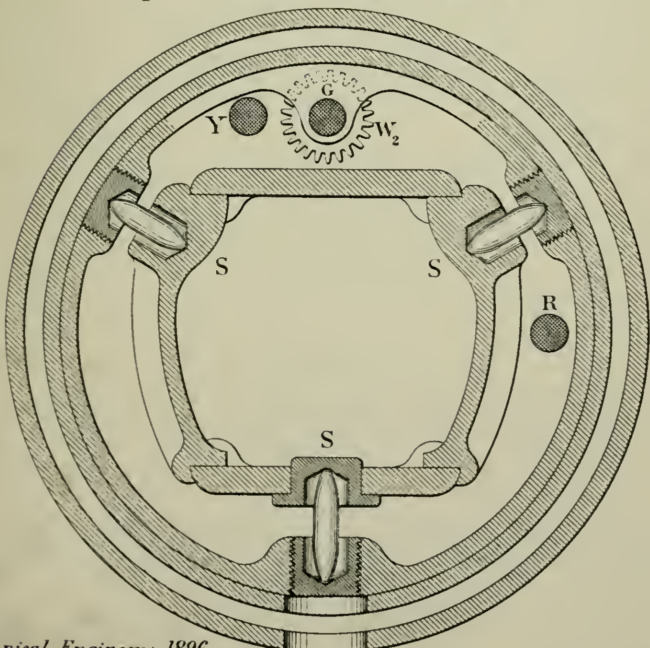


Fig. 33. *Driving Gear, and Coincidence Adjustment.*

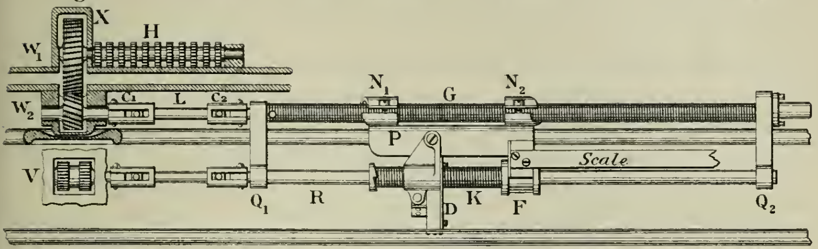
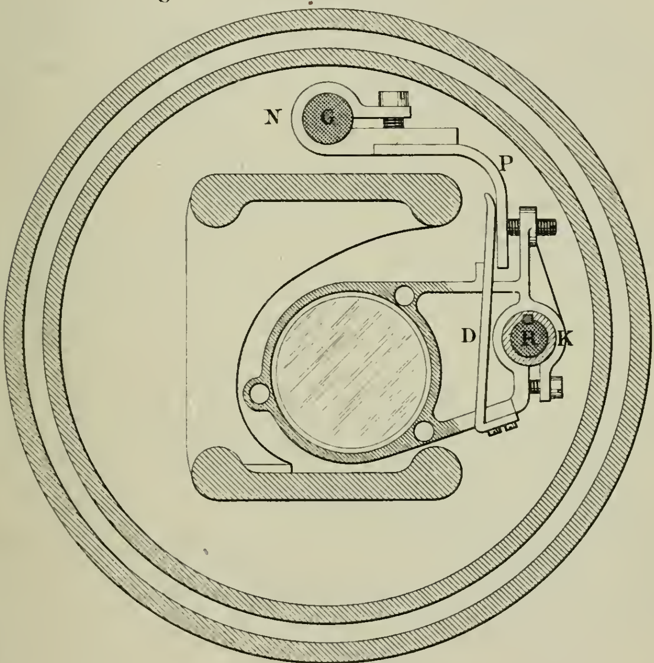


Fig. 34. *Refracting - Prism Gear.*



Coupling.

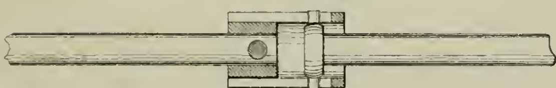


Fig. 35.

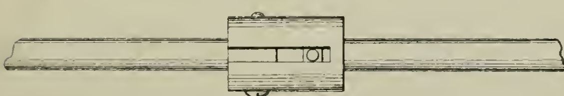


Fig. 36.

Fig: 37. *Frame-work.*

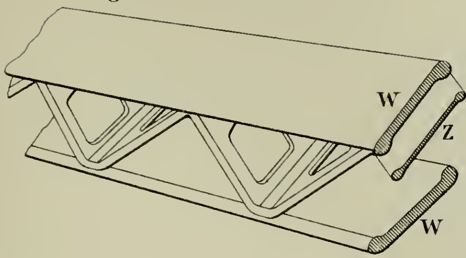


Fig: 38.

Radiation.

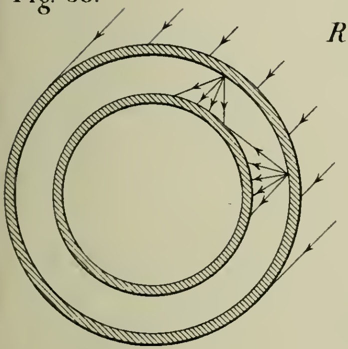


Fig: 39.

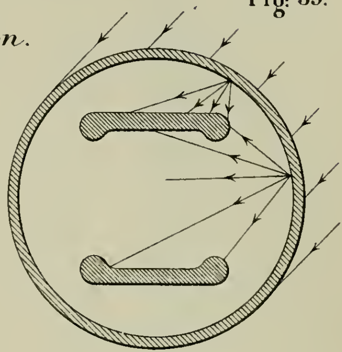


Fig: 40. *Halving Gear.*

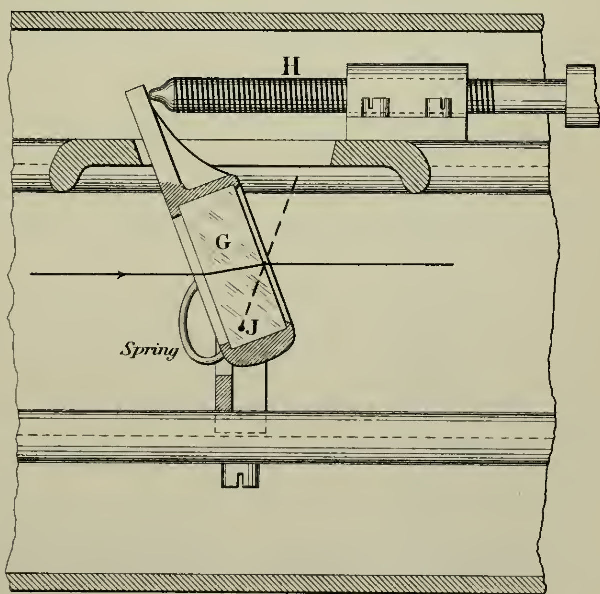


Fig: 41.

MARINE HORSE-POWER.

Model-Testing Apparatus in Dock.

Fig. 1. *Plan.*

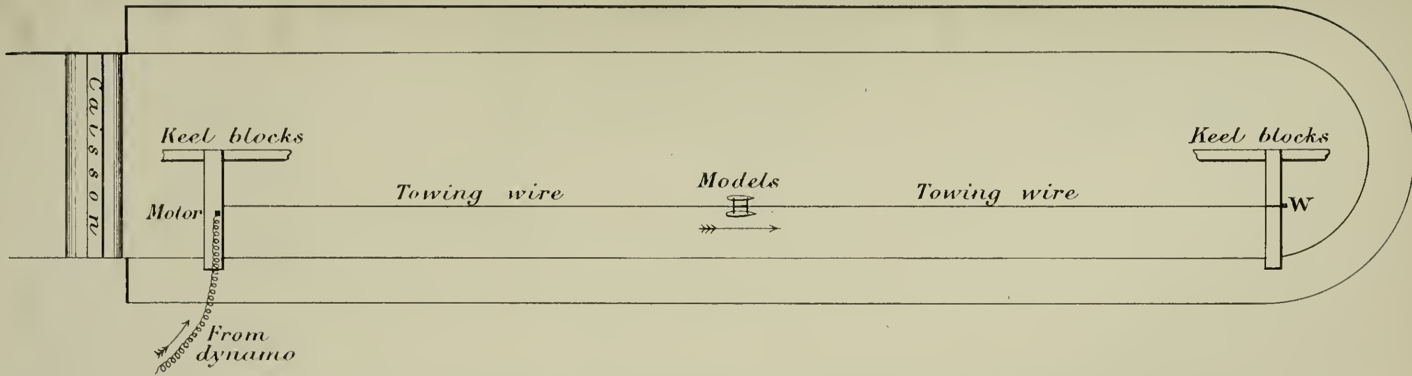
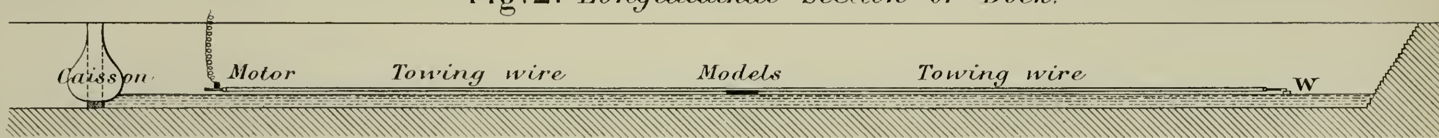


Fig. 2. *Longitudinal Section of Dock.*



Scale 64 feet per inch.

Plate 13.

MARINE HORSE-POWER.

Model-Testing Apparatus.

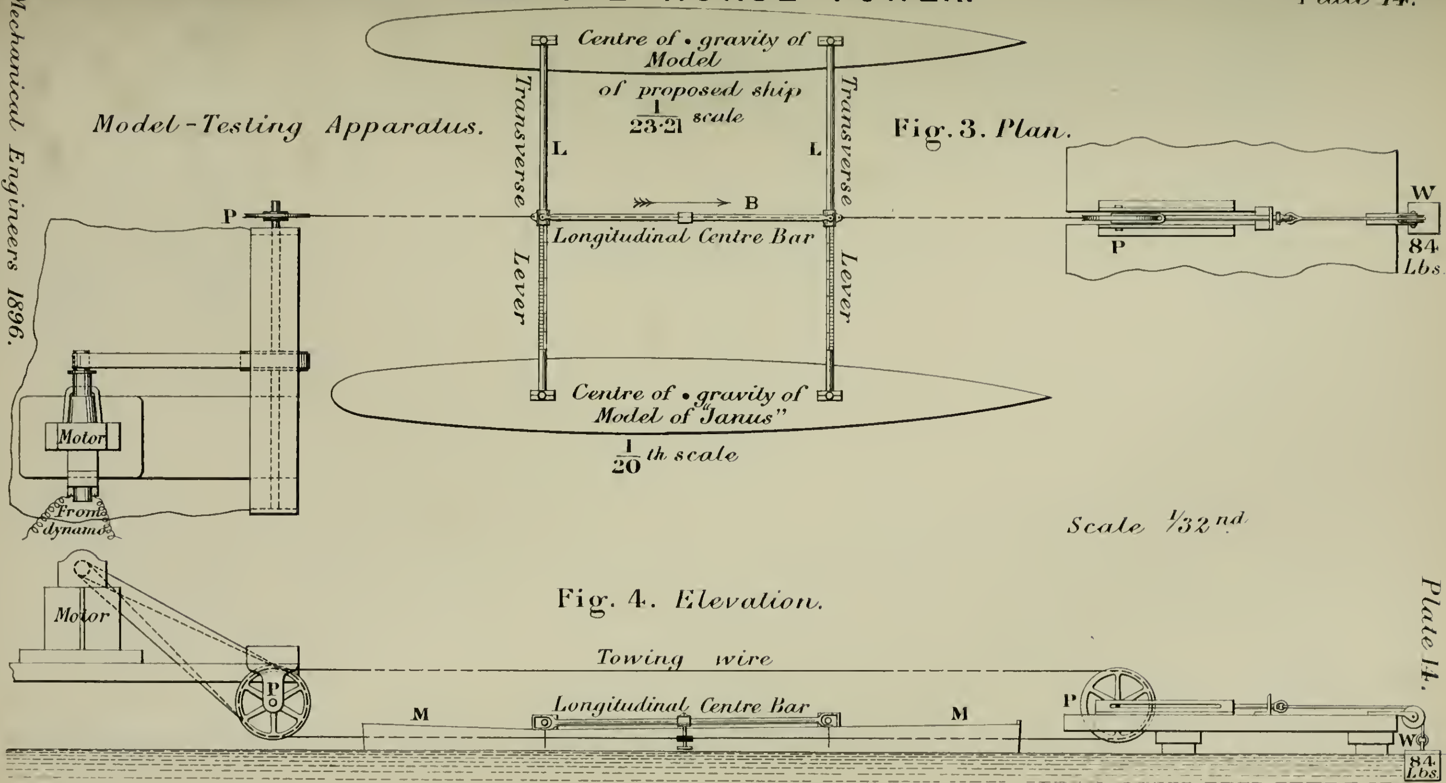


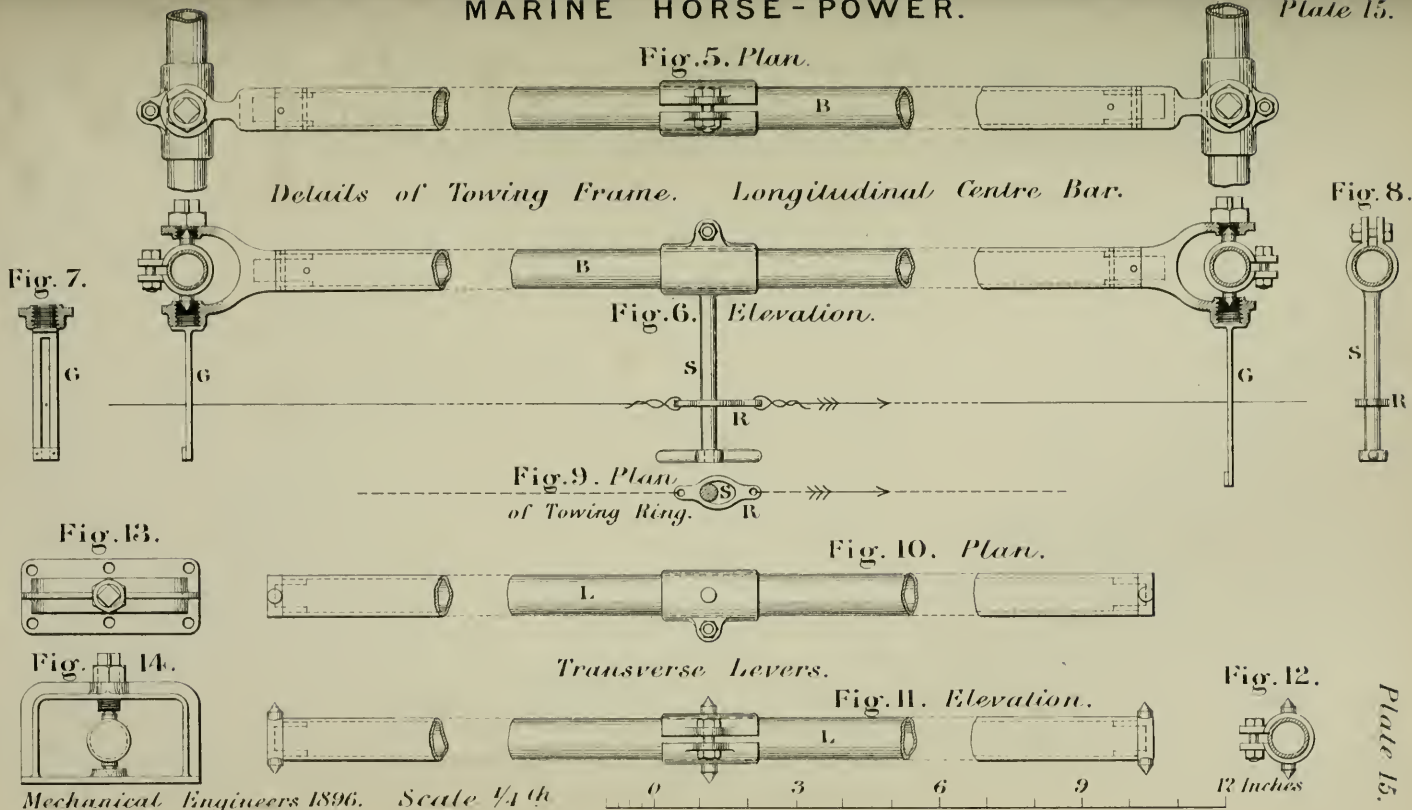
Fig. 3. Plan.

Scale 1/32nd.

Fig. 4. Elevation.

Plate 14.

MARINE HORSE-POWER.



Mechanical Engineers 1896. Scale 1/4 th

Plate 15.

MARINE HORSE-POWER.

Fig: 15.

Skin Resistances of Models.

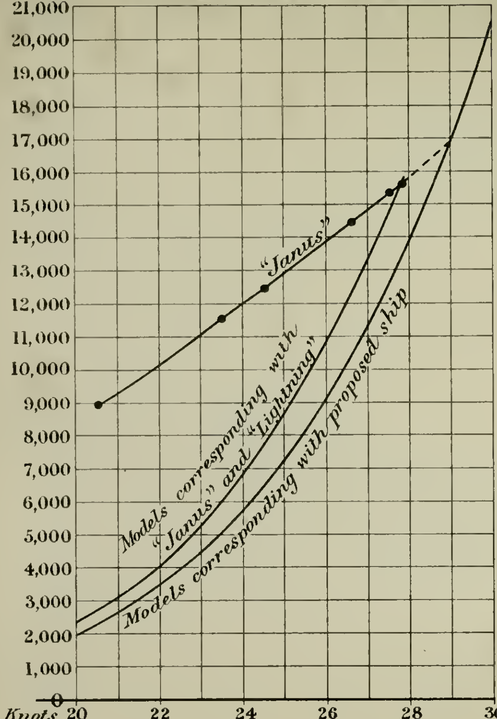


Fig: 16.

Wave Resistances of Models.

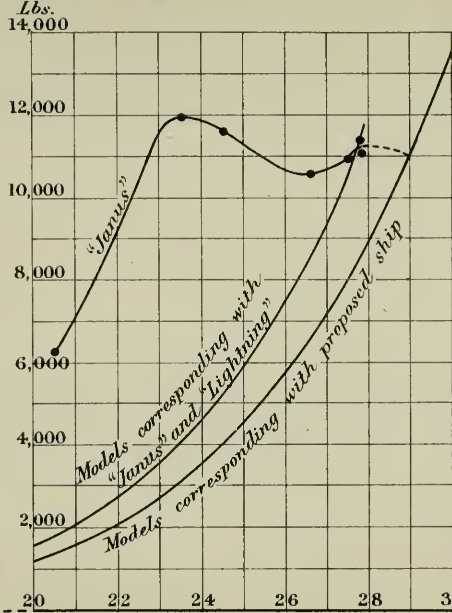
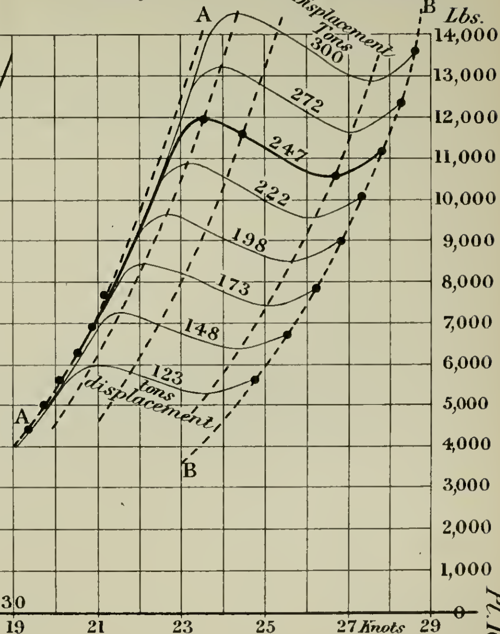


Fig: 17.

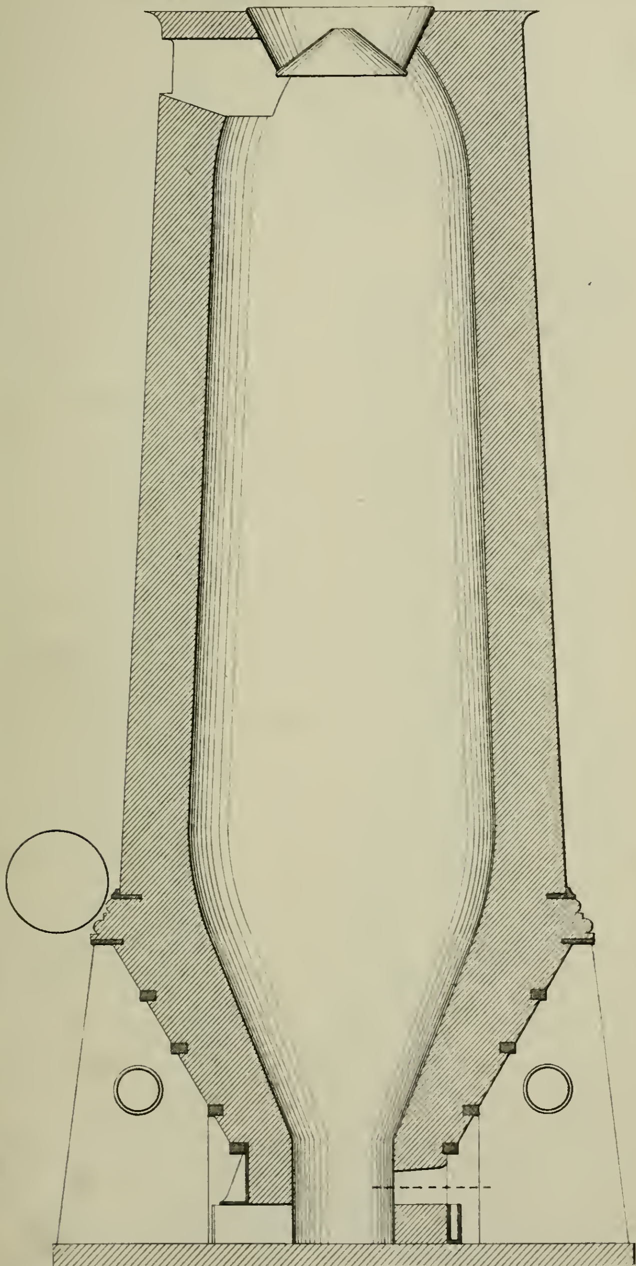
Wave Resistances calculated for various displacements from progressive speed trials of "Janus"



Speed in Knots

Fig. 1. *Cleveland Iron Works, Eston.*

Old lines of No. 8 Furnace.



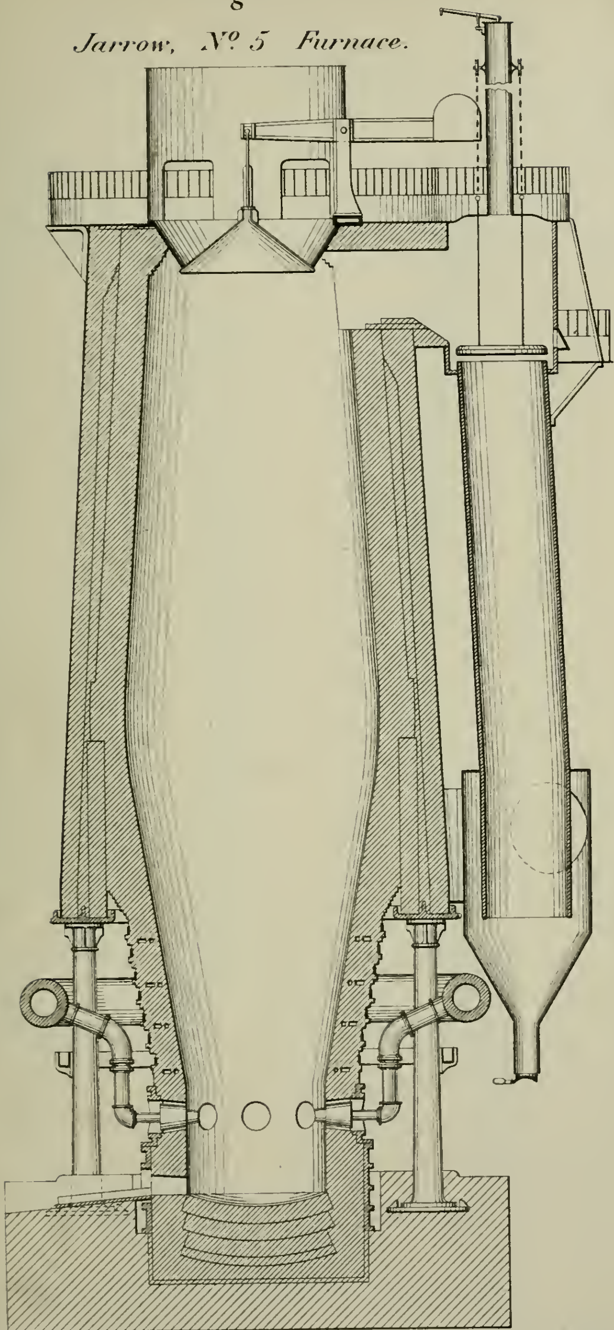
Mechanical Engineers 1896.

Scale 1/180th

Feet 10 5 0 10 20 30 40 Feet

Fig: 2.

Jarrow, Nº 5 Furnace.



Mechanical Engineers 1896.

Scale 1/180th.

Feet 10 5 0 10 20 30 40 Feet

Fig. 3.
Jarrow, No. 5 Furnace.
Alteration of Bosh.

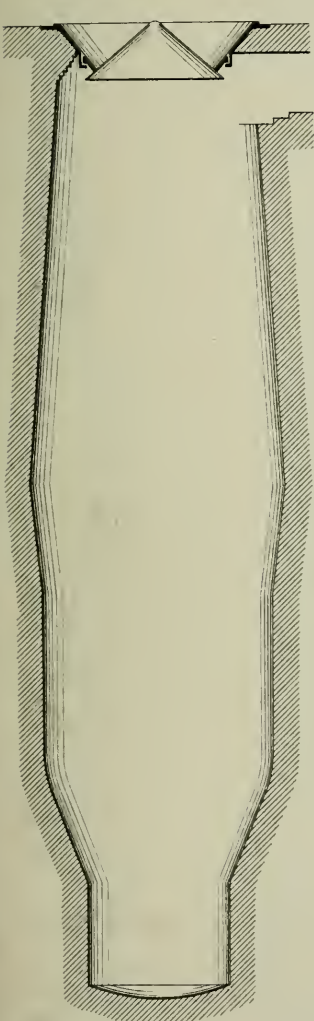
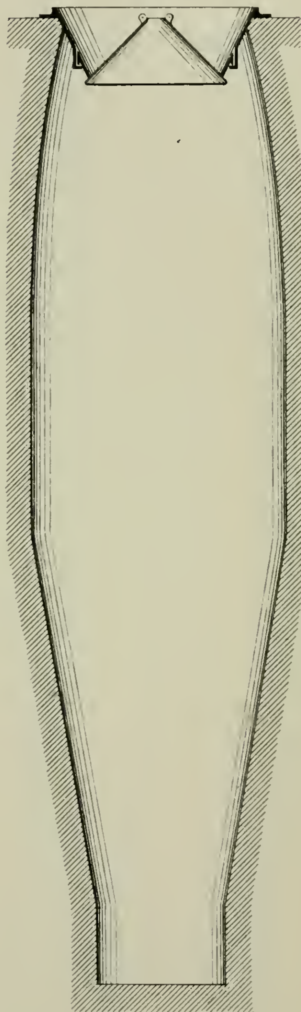


Fig. 4.
Dowlais, Cardiff.
No. 2 Furnace.



Mechanical Engineers 1896.

Scale 1/180th.

Feet 10 5 0 10 20 30 40 Feet

Fig: 5.
Newport,
No. 5 Furnace.

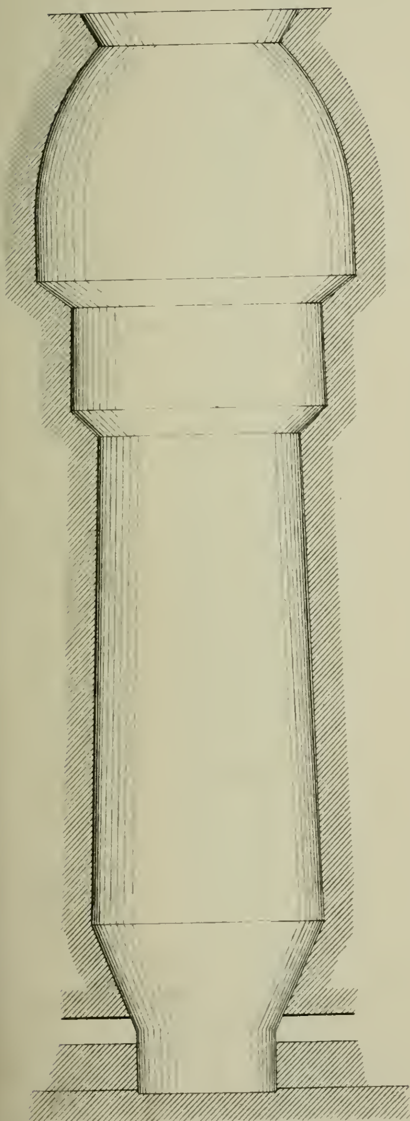
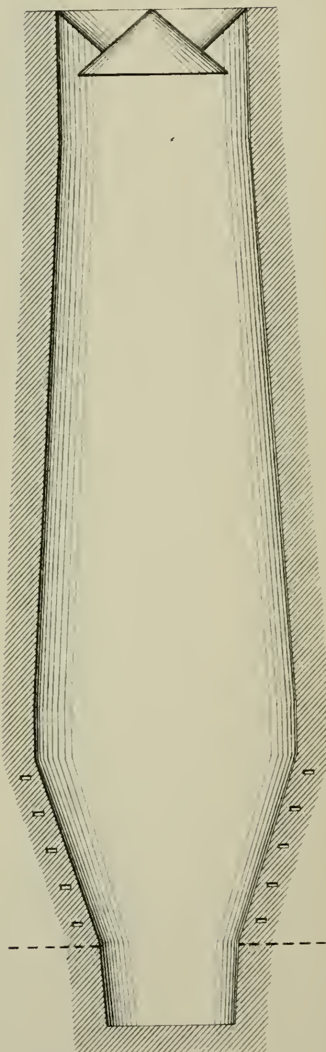


Fig: 6.
Cockerill,
No. 5 Furnace.

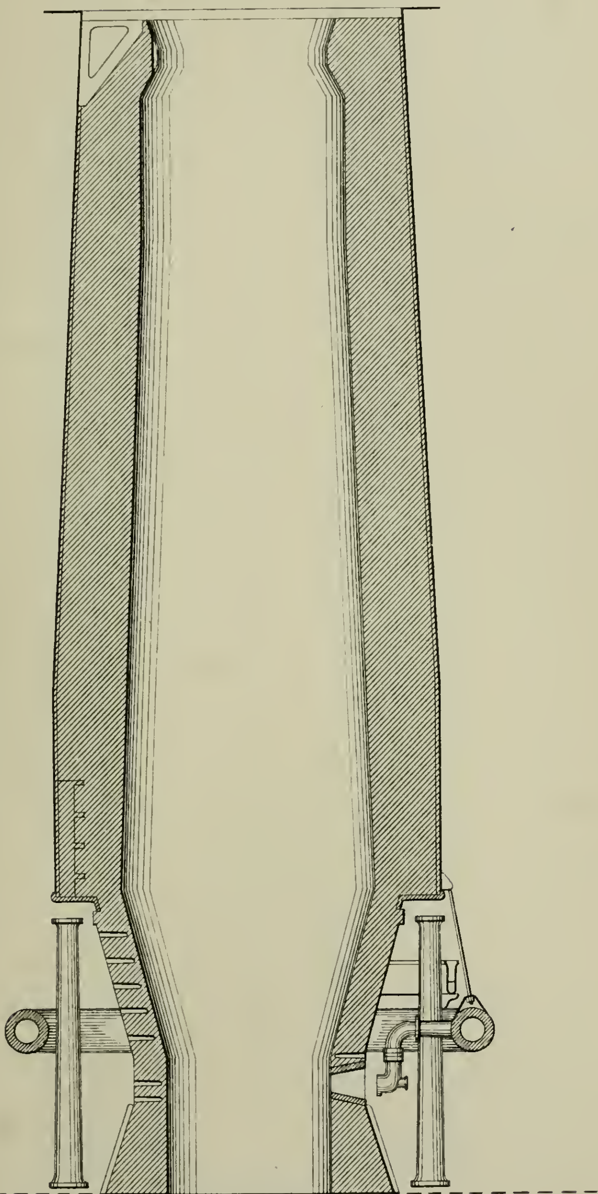


Scale 1/180th

Feet 10 5 0 10 20 30 40 Feet

Fig. 7. *Edgar Thomson Furnace.*

Second Lining of Furnace H.



Mechanical Engineers 1896.

Scale 1/180th

Feet 10 5 0 10 20 30 40 Feet

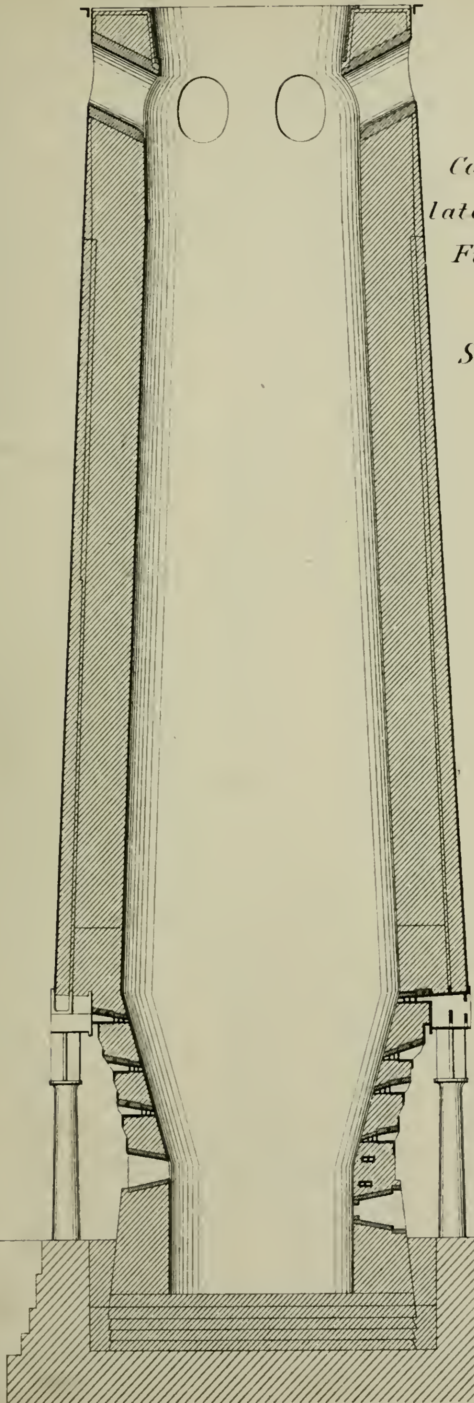
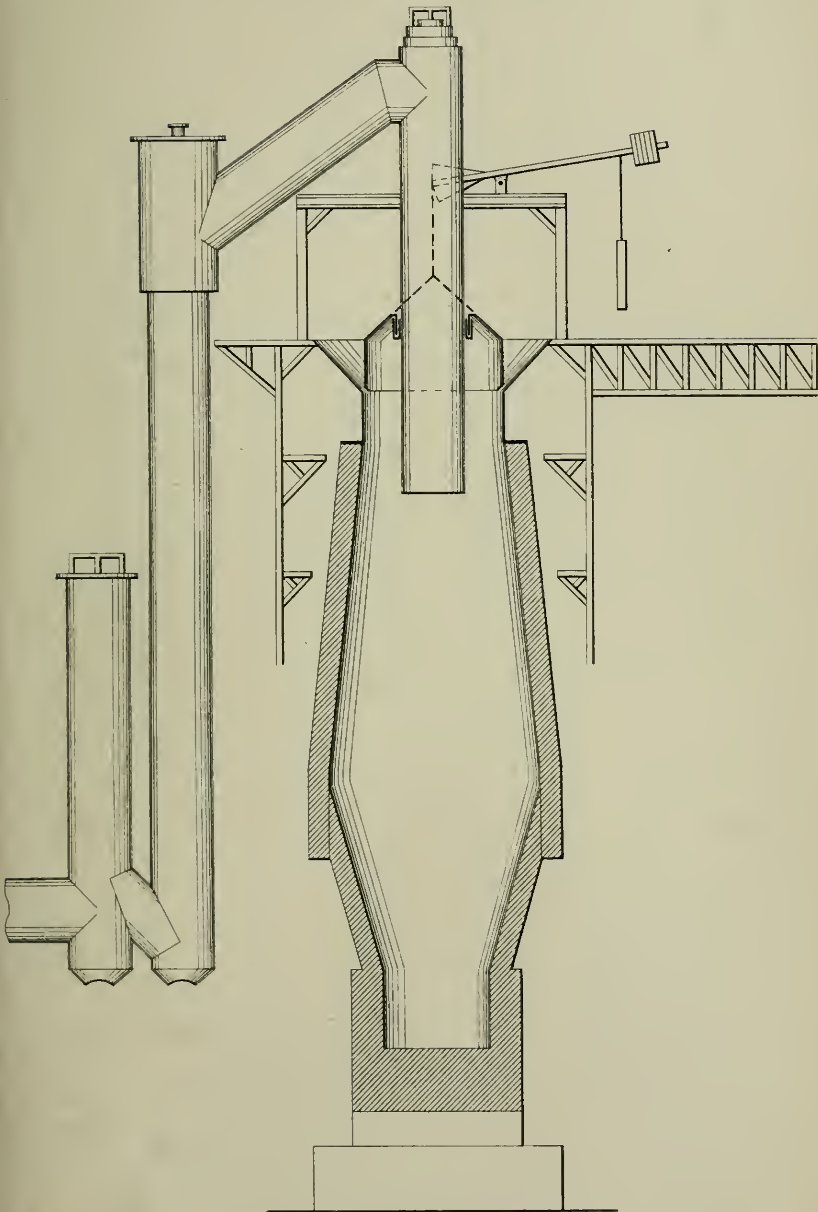


Fig. 8.
Carnegie latest new Furnace.

Scale 1/180th

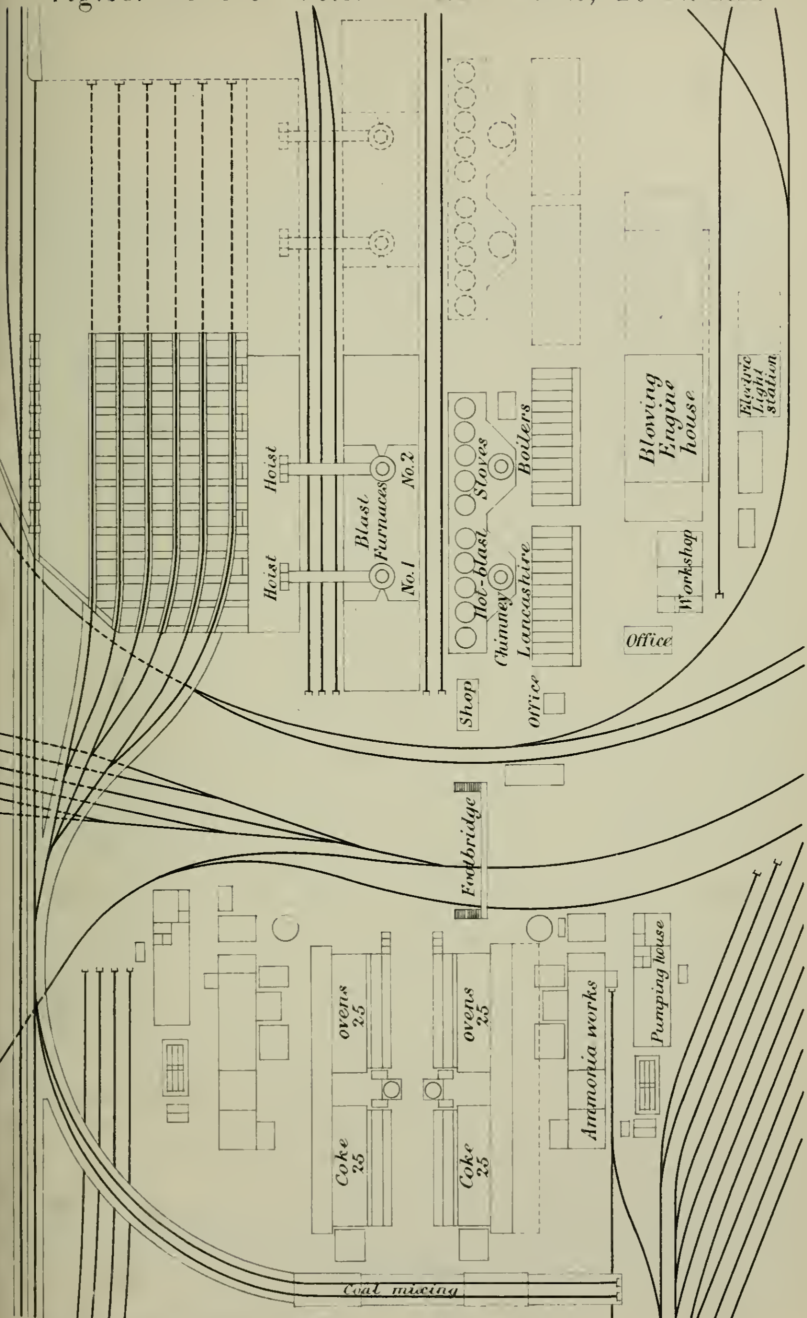
Fig. 9. *Hoesch Furnace.*



Mechanical Engineers 1896.

Scale 1/240th.

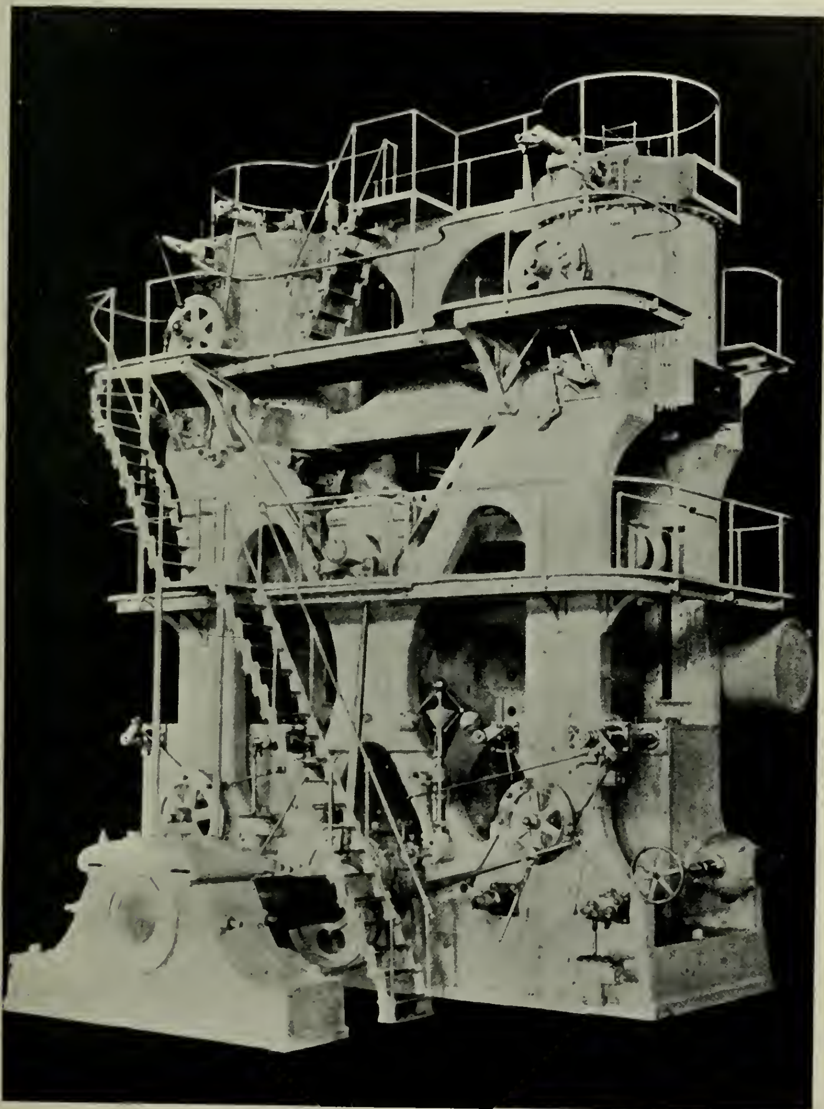
Fig. 10. Plan of Hoesch Steel Works, Dortmund.



 Scale 200 feet to an inch

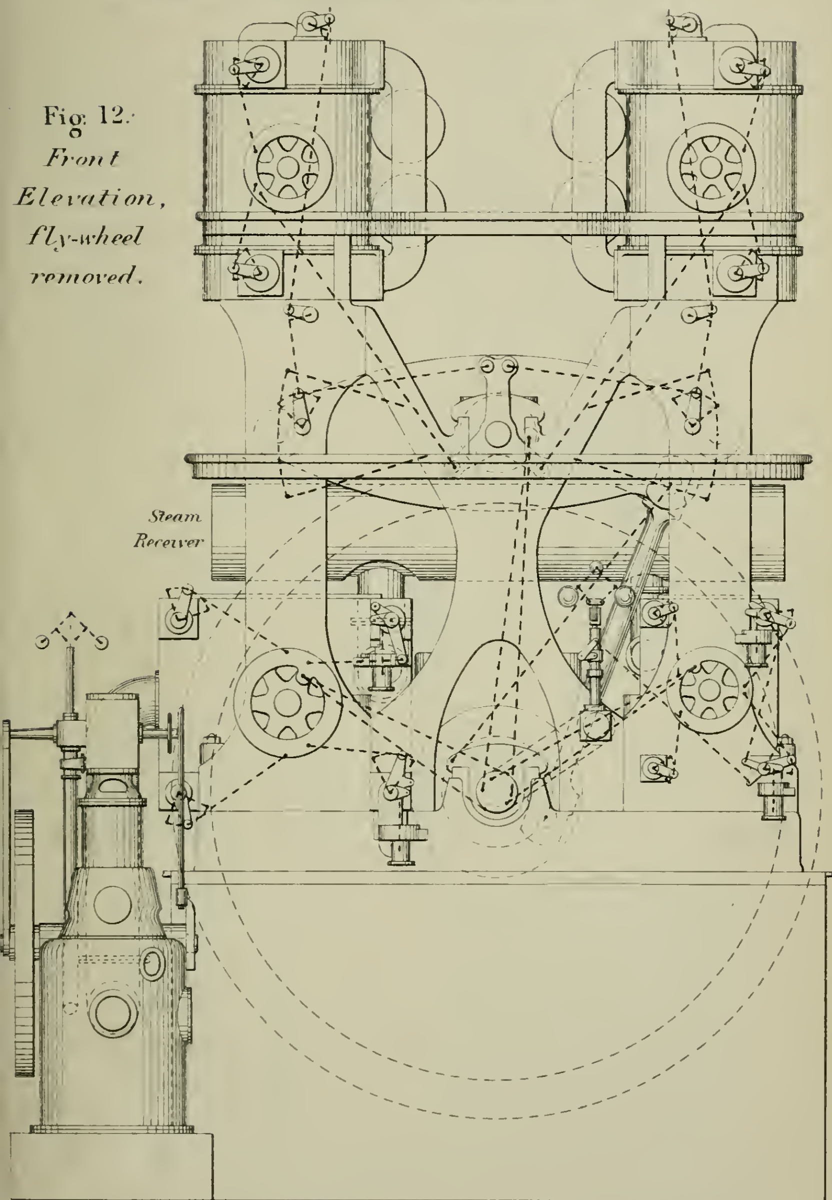
Feet 100 50 0 100 200 300 400 500 600 Feet.

Fig. 11. *Vertical Compound Blowing Engine at Carnegie Duquesne Steel Works, Pittsburg.*



Vertical Compound Blowing Engine.

Fig: 12.
Front Elevation, fly-wheel removed.



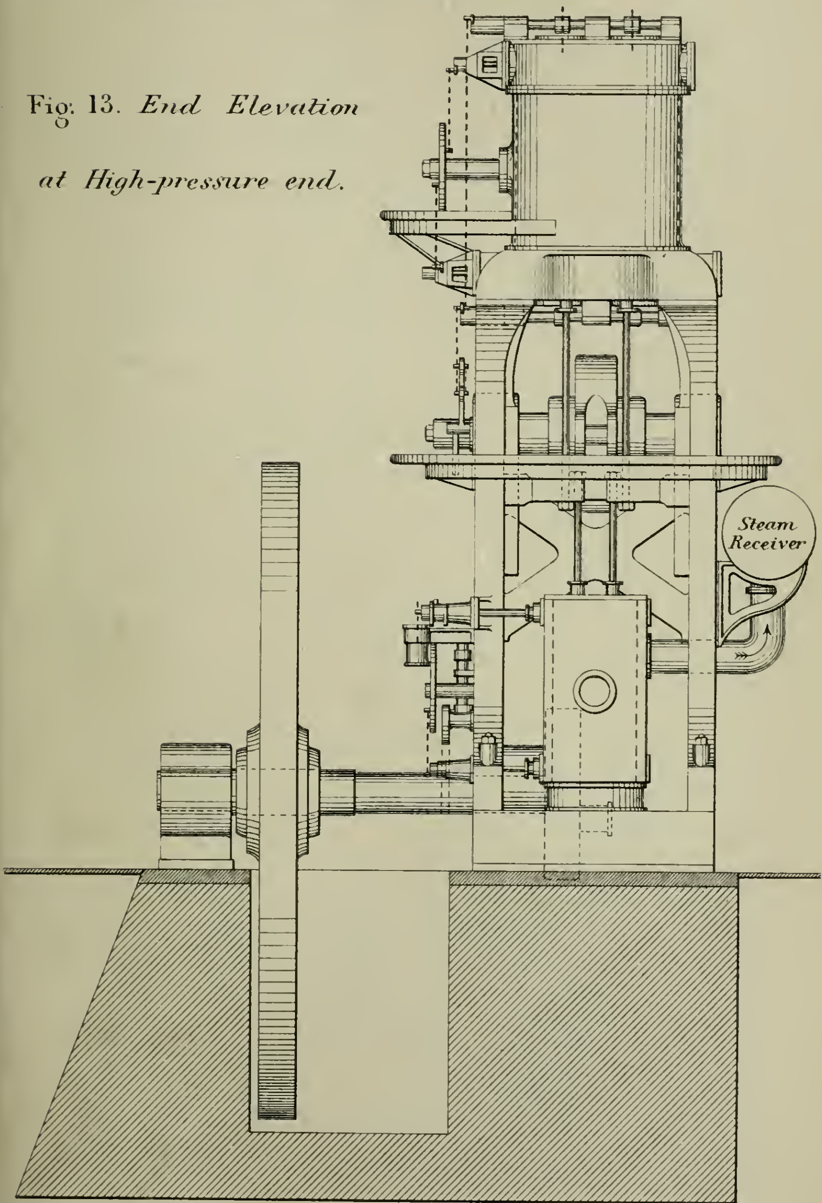
 Scale 1/90th

0 5 10 15 20 25 Feet

Vertical Compound Blowing Engine.

Fig. 13. *End Elevation*

at High-pressure end.



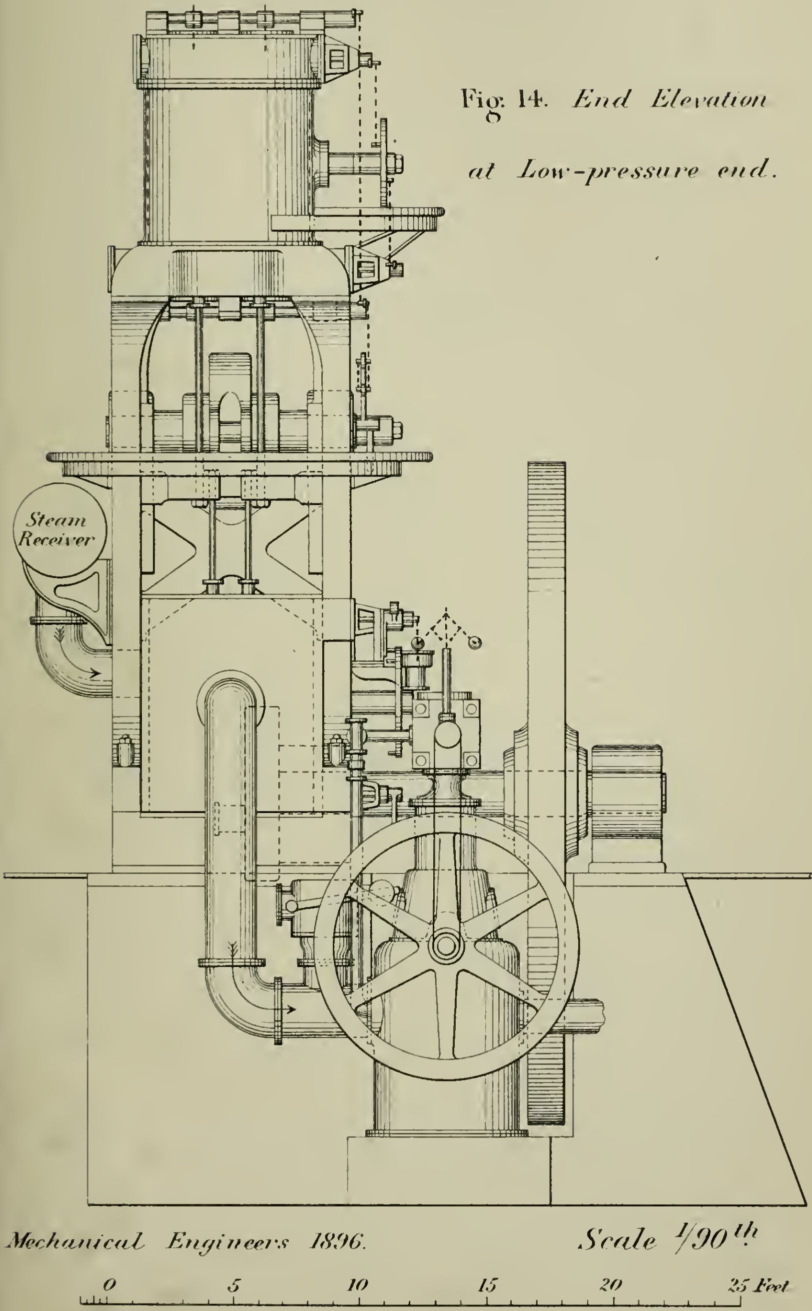
Mechanical Engineers 1896.

Scale 1/90th.

0 5 10 15 20 25 Feet

Vertical Compound Blowing Engine.

Fig. 14. *End Elevation at Low-pressure end.*

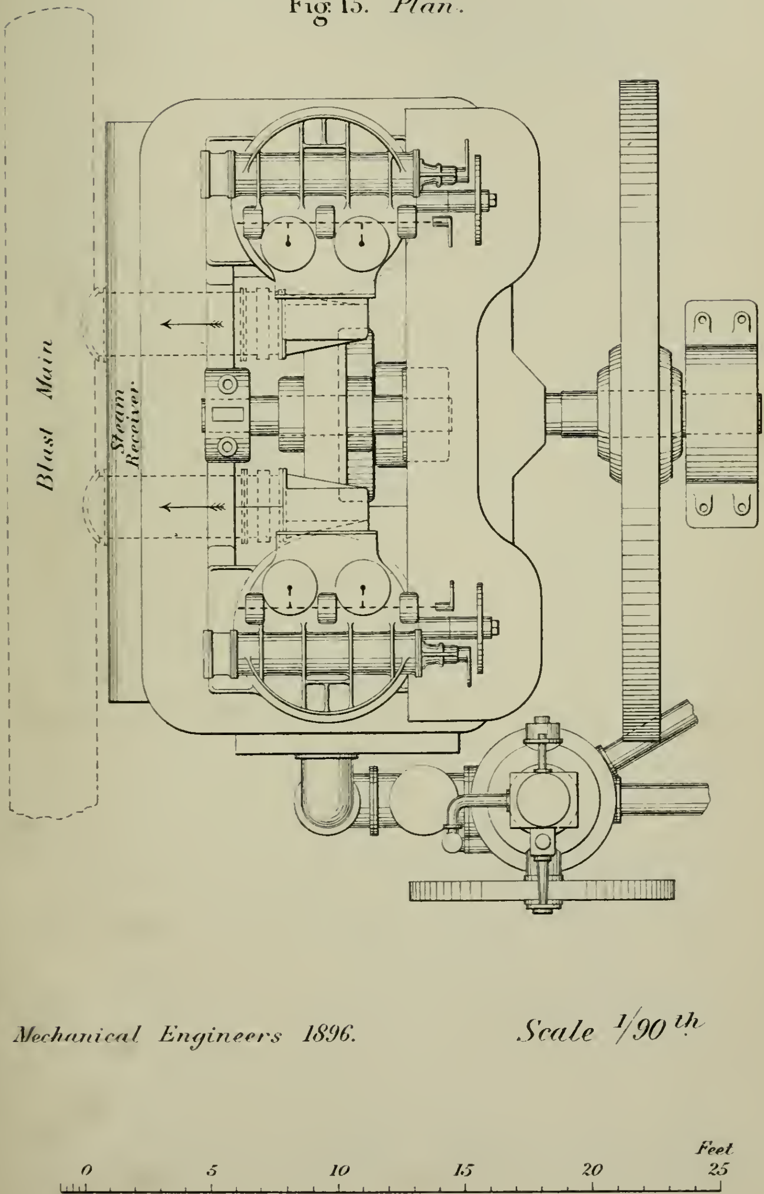


Mechanical Engineers 1896.

Scale 1/90th.

Vertical Compound Blowing Engine.

Fig. 15. *Plan.*



Scale 1/90 th.

STEAM SUPERHEATING. *Plate 30.*

Trevithick.

Fig. 1. *Plan, with covers removed.*

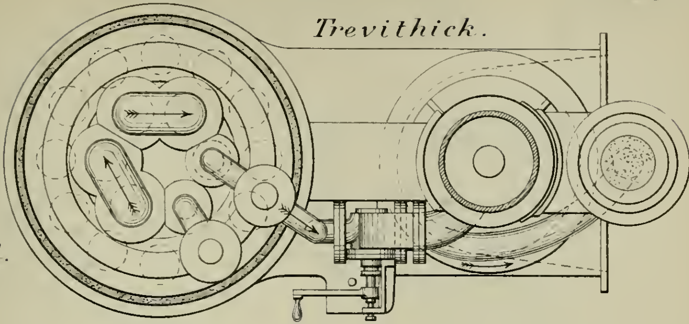
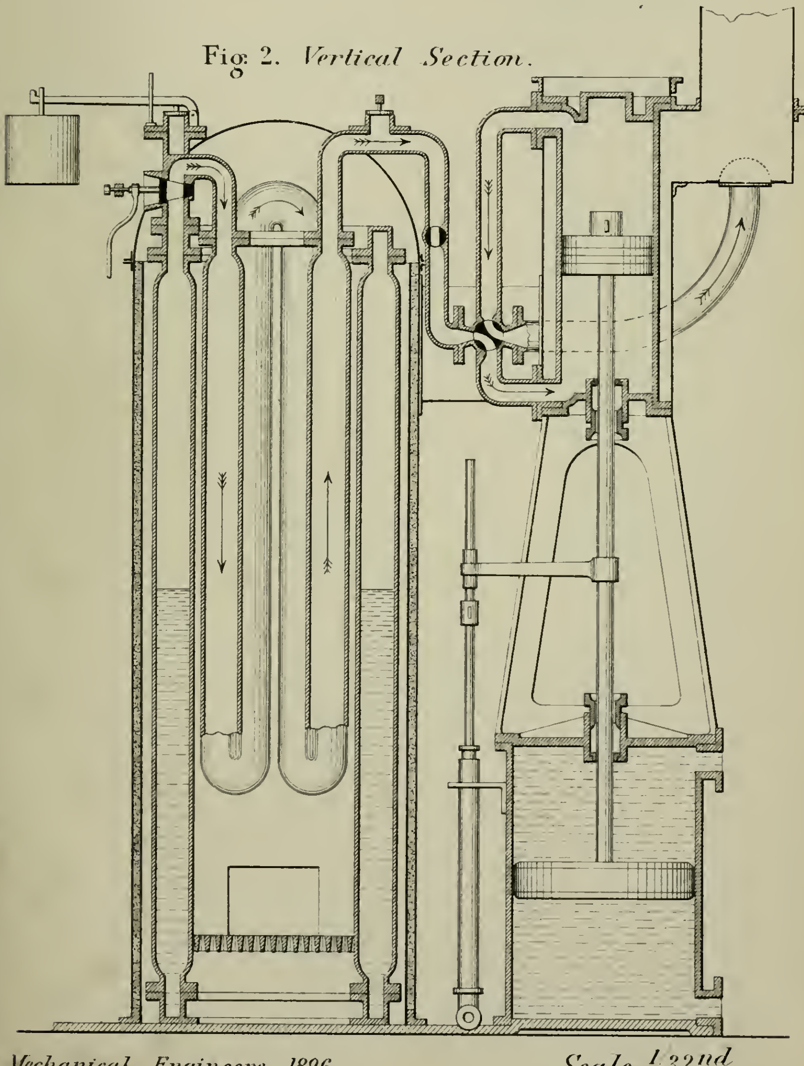


Fig. 2. *Vertical Section.*



Scale 1/32nd.

STEAM SUPERHEATING.

Gehre, in boiler flue.

Fig: 3. *Transverse Section.*

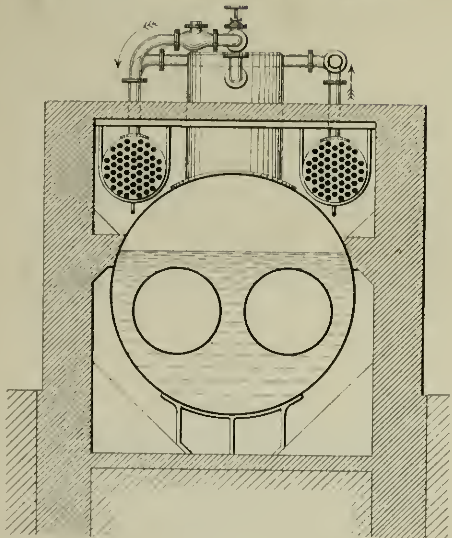
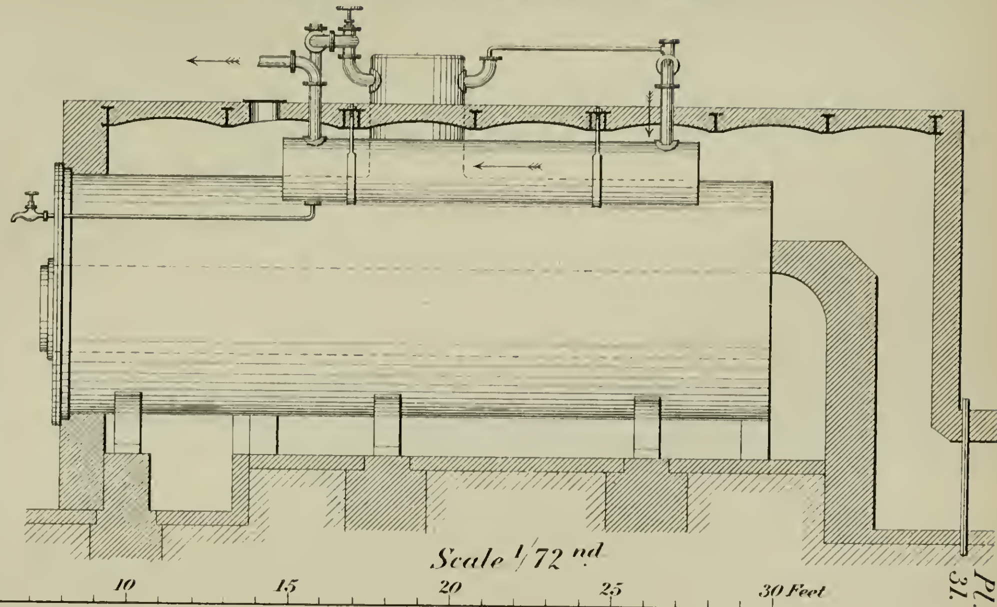


Fig: 4. *Longitudinal Section.*



Scale 1/72 nd.

STEAM SUPERHEATING.

Gehre,
separately fired.

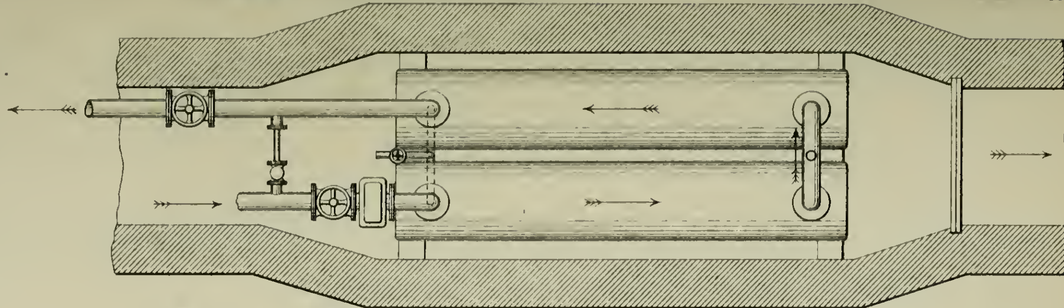


Fig: 5.
Sectional Plan.

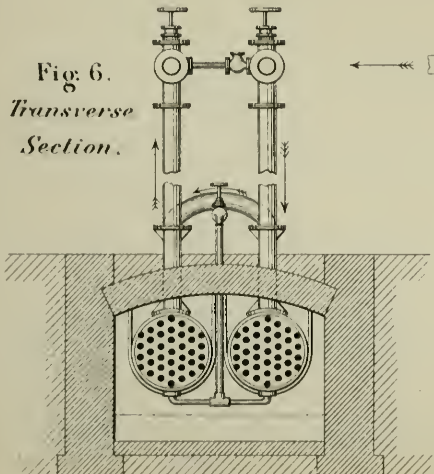
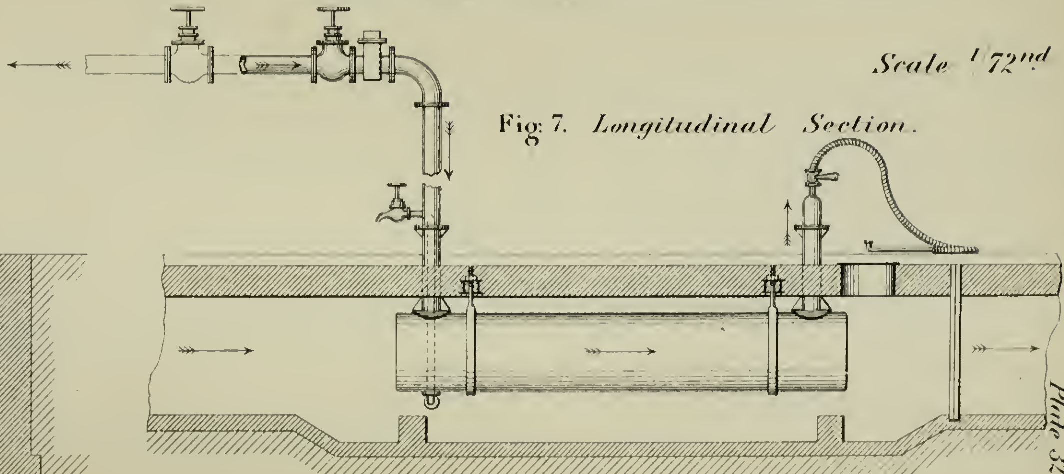


Fig: 6.
Transverse Section.



Scale 1/72nd

Fig: 7. Longitudinal Section.

Plate 32.

STEAM SUPERHEATING.

Musgrave and Dixon.

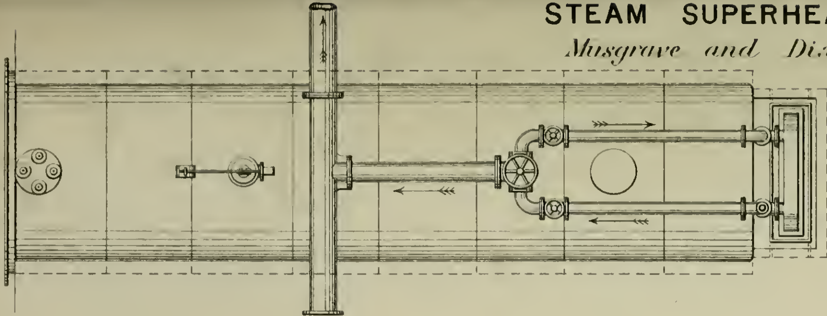


Fig: 8. *Plan.*

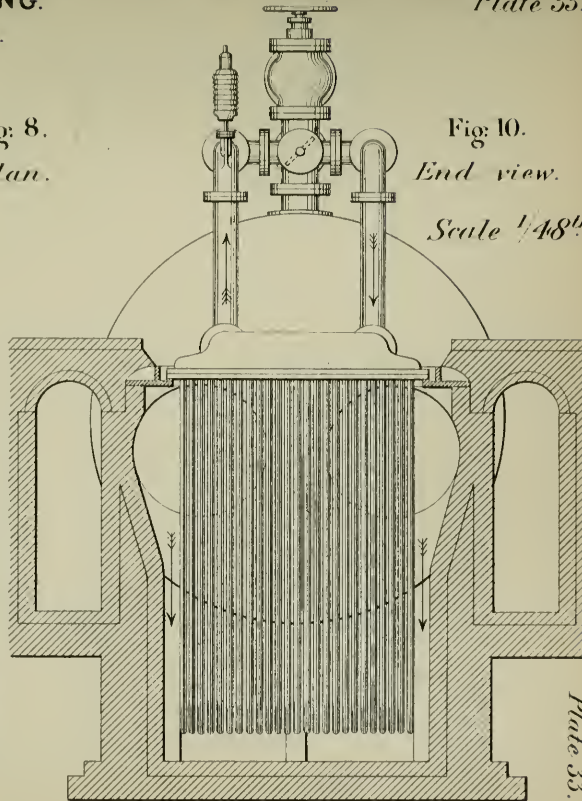
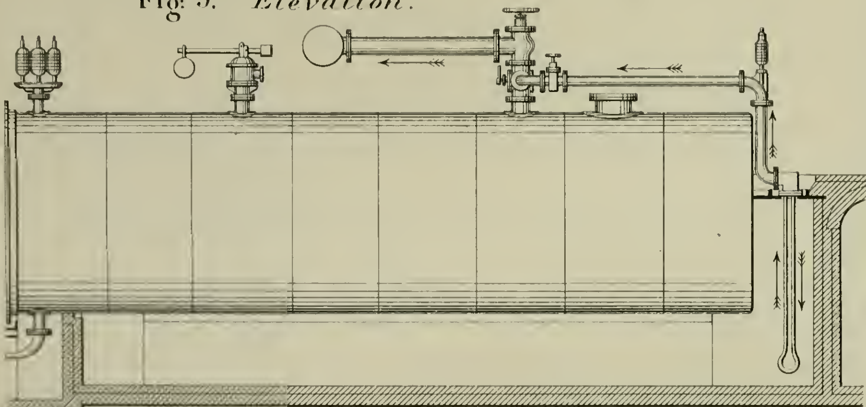


Fig: 10. *End view.*

Scale 1/48th.

Fig: 9. *Elevation.*



Scale 1/96th.

Plate 33.

Mc Phail and Simpsons.

Fig: 11. *Sectional Plan, above flues.*

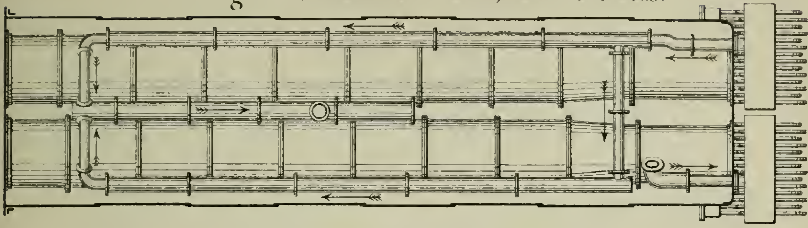
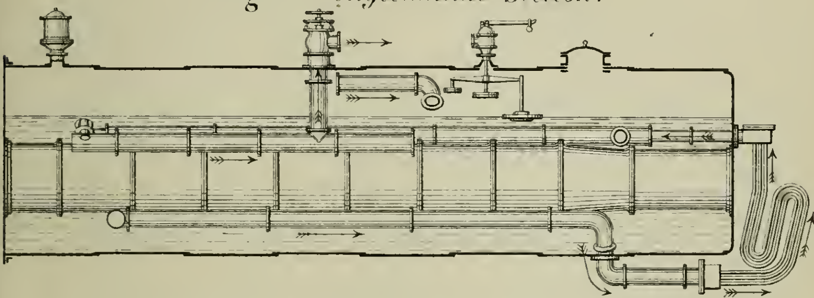


Fig: 12. *Longitudinal Section.*



Scale 1/96th.

Fig: 13. *Sectional Plan, under flues.*

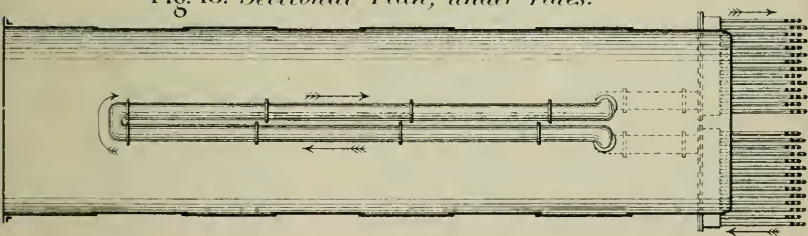


Fig: 14. *Transverse Section.*

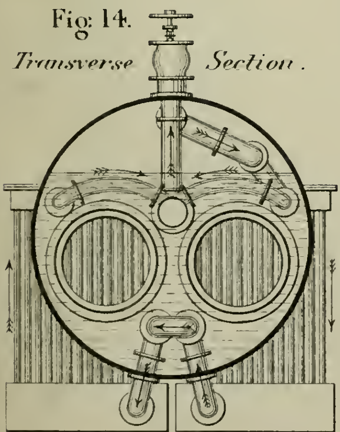
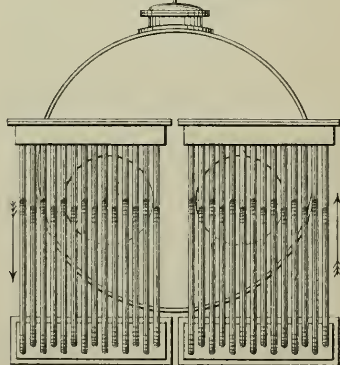


Fig: 15. *Back View.*



Mechanical Engineers 1896.

Scale 1/64th.

STEAM SUPERHEATING.

Mc Phail and Simpsons.

Fig: 16. *Sectional Plan.*

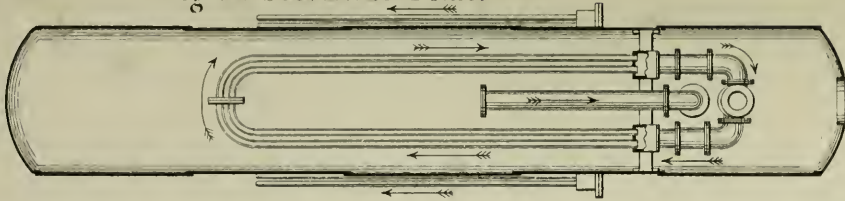


Fig: 17. *Longitudinal Section.*

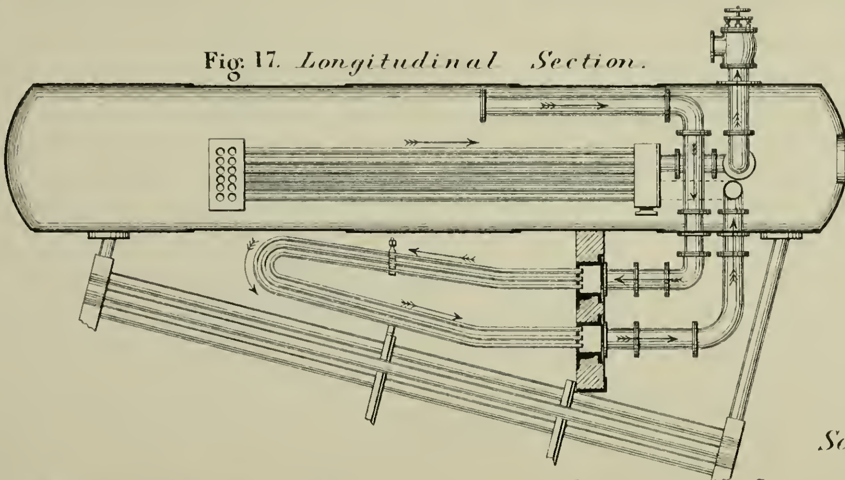


Fig: 18. *Transverse Section.*

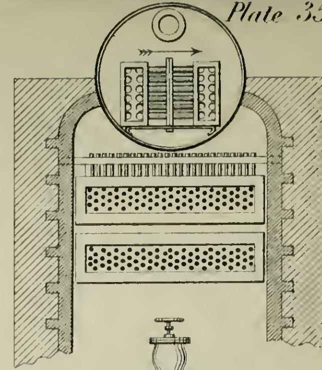
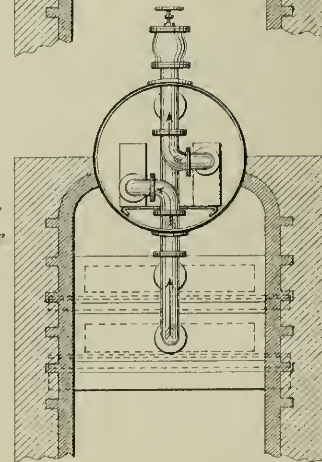


Fig: 19. *Transverse Section.*



Scale 1/64th

Plate 35.

STEAM SUPERHEATING.

Schwoerer.

Fig: 20. *Elevation.*

Fig: 21. *End view.*

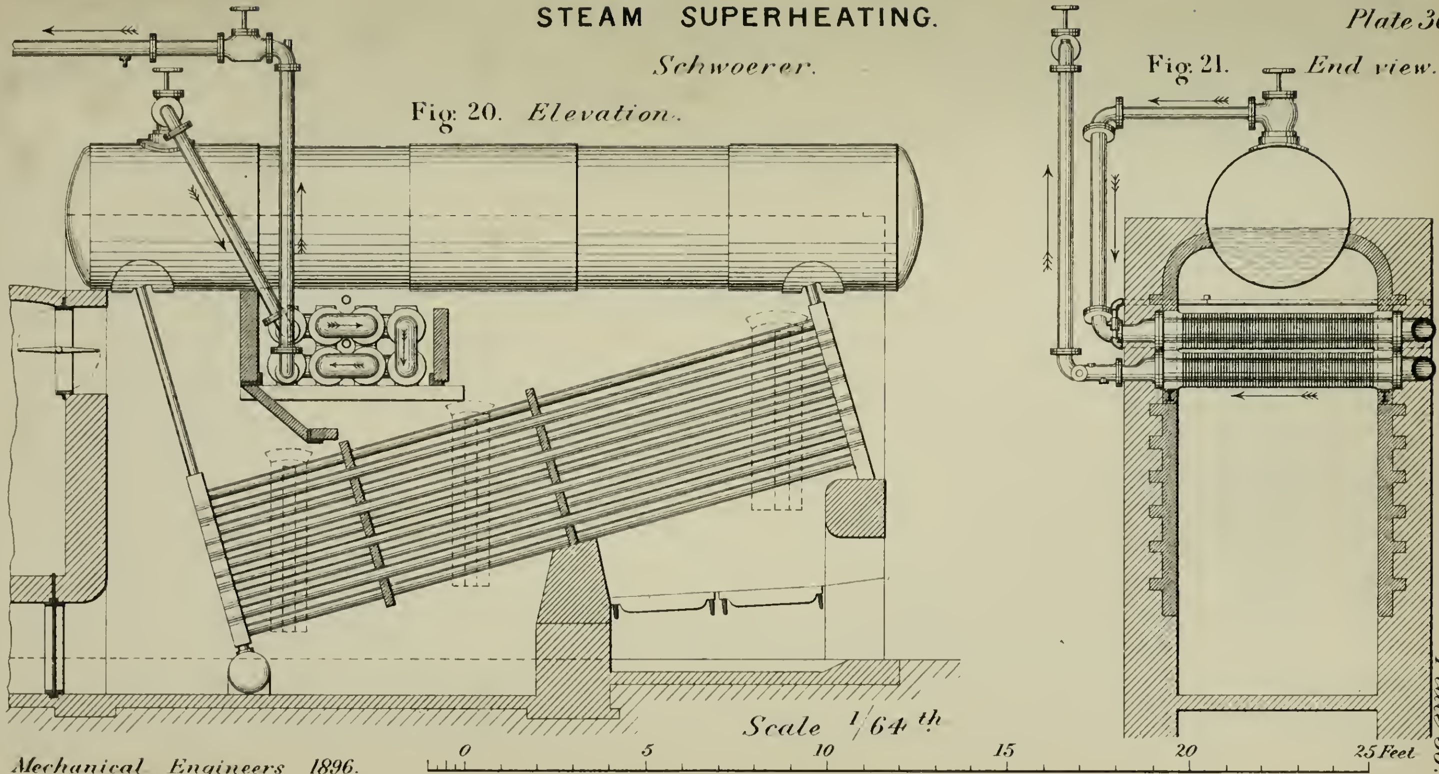


Plate 36.

STEAM SUPERHEATING.

Schwoerer.

Fig: 22. *Plan.* *Scale 1/64th*

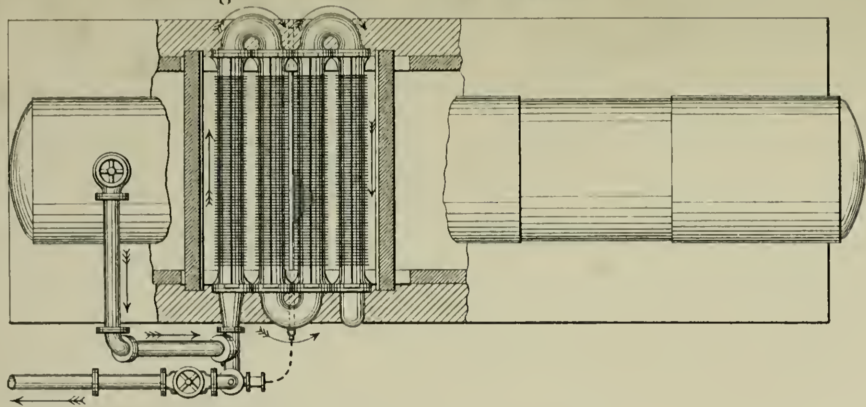


Fig: 23. *Scale 1/32nd*

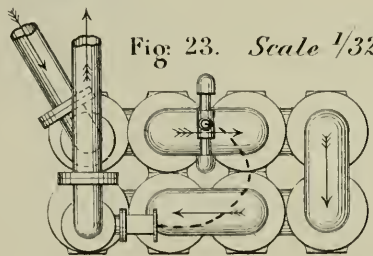
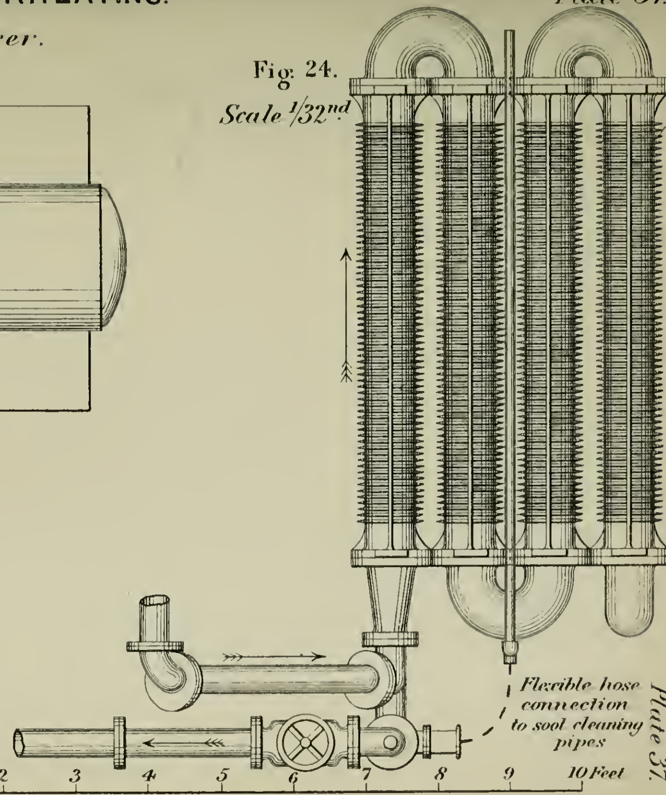


Fig: 24. *Scale 1/32nd*



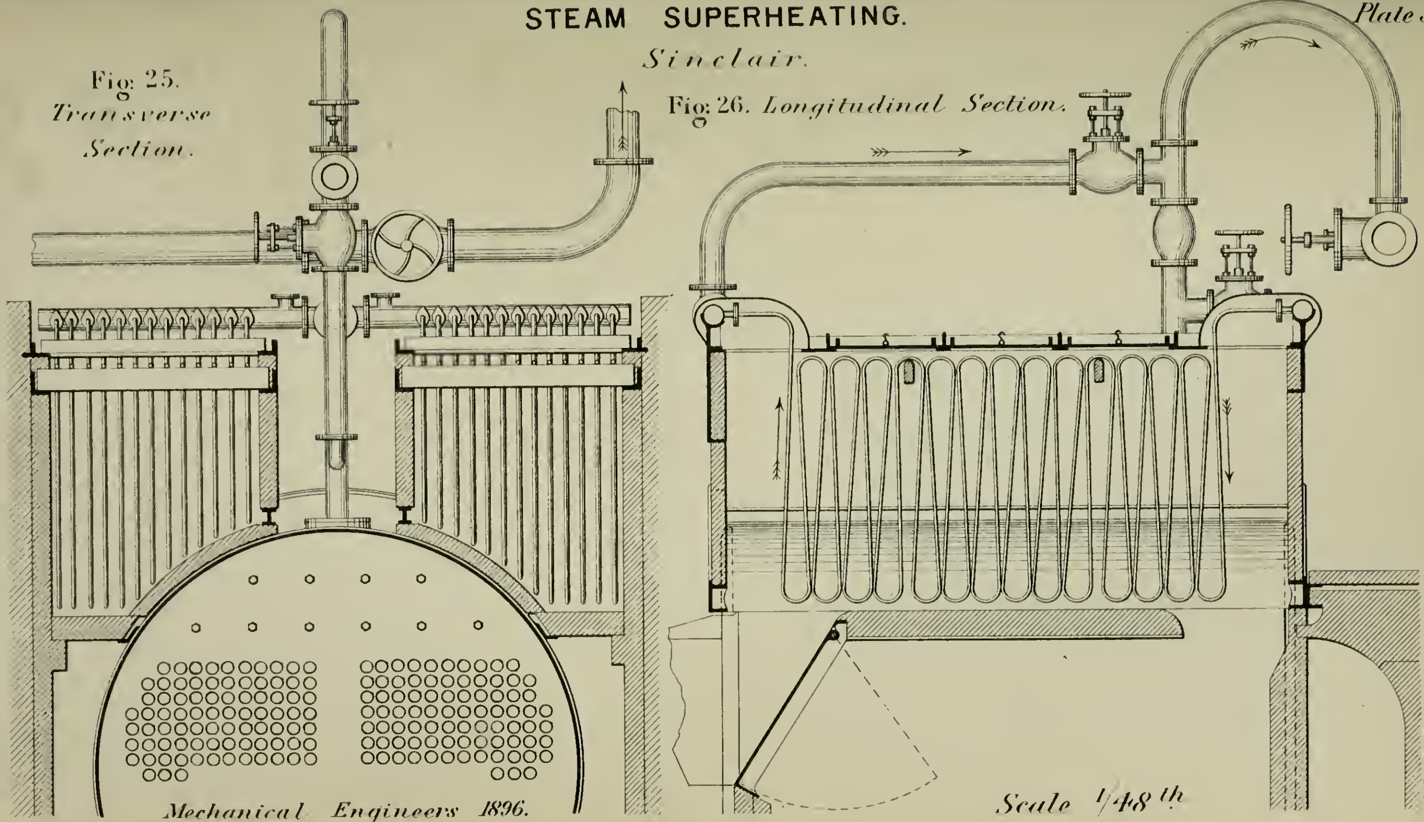
Scale 1/32nd

STEAM SUPERHEATING.

Sinclair.

Fig: 25. *Transverse Section.*

Fig: 26. *Longitudinal Section.*



Scale $^1/_{48}{}^{th}$.

Mechanical Engineers 1896.

Plate 38.

STEAM SUPERHEATING.

Holt.

Fig: 27.

Longitudinal Section.

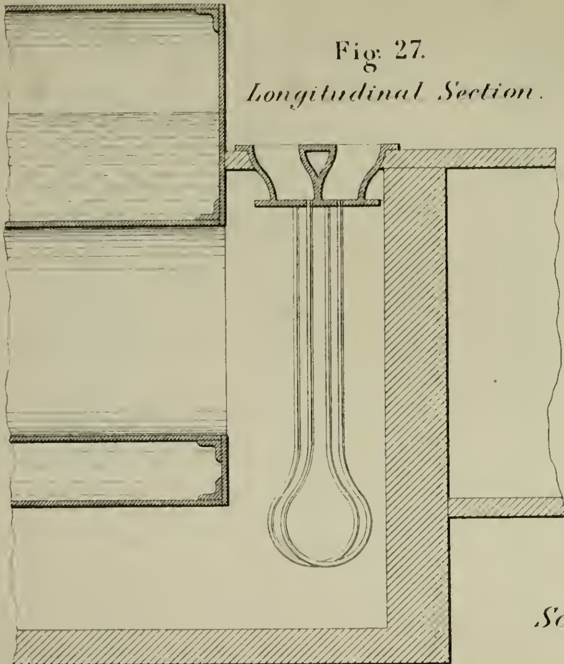
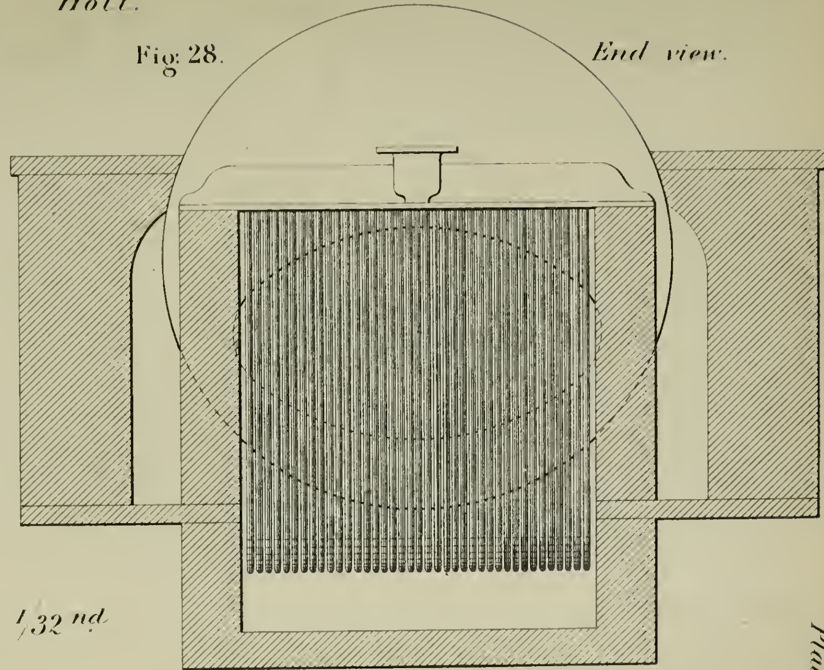


Fig: 28.

End view.



Scale $^{1}/_{32}$ nd.

Plate 39.

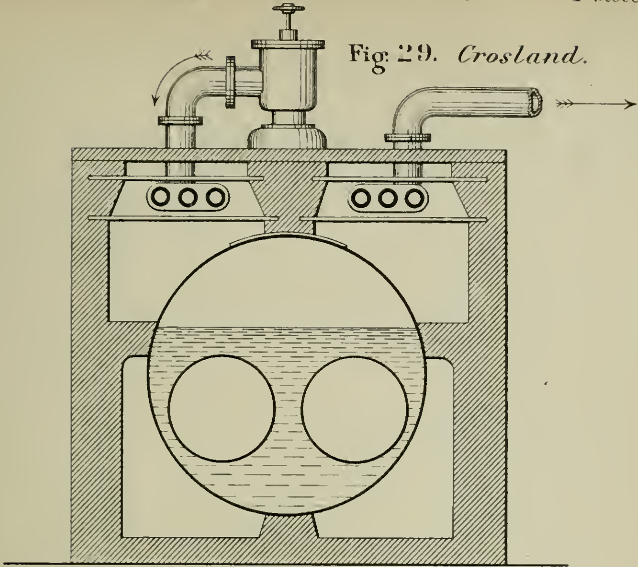


Fig: 29. *Crosland.*

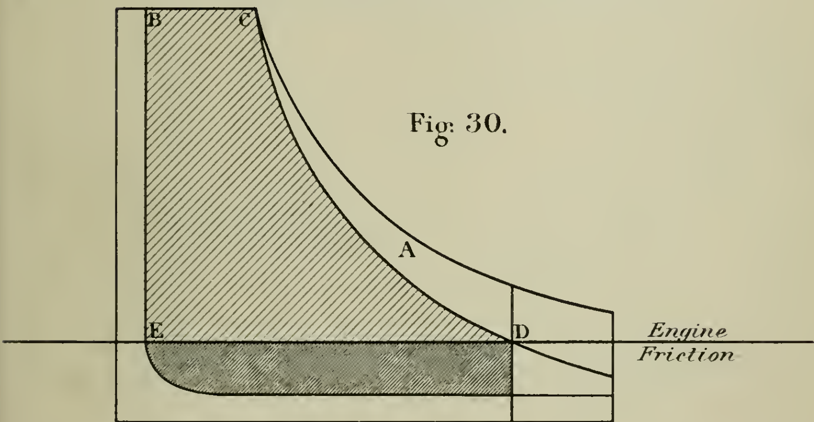


Fig: 30.

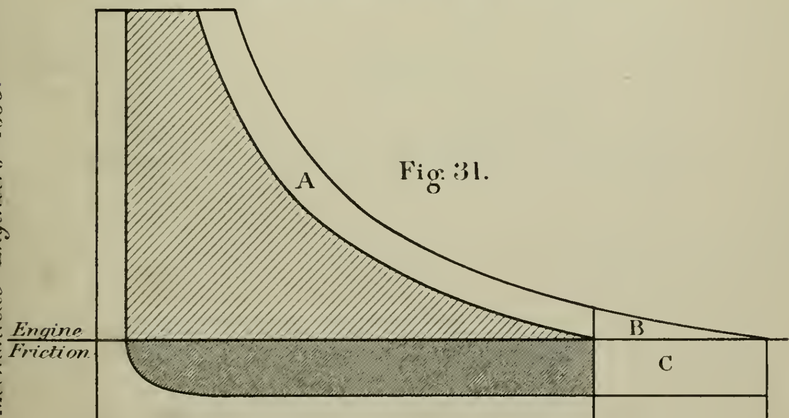


Fig: 31.

Mechanical Engineers 1896.

STEAM SUPERHEATING.

Boulton.

Fig. 32. *Longitudinal Section.*

Scale 1/32nd.

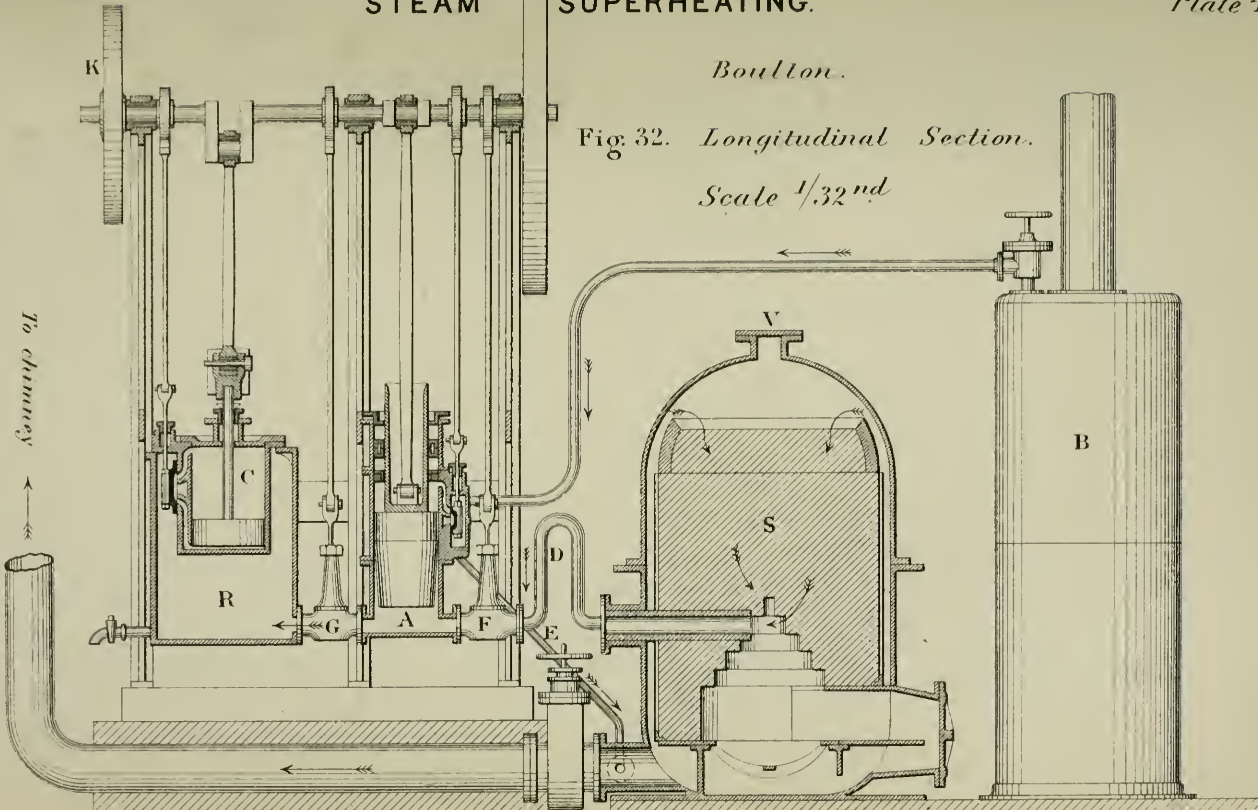


Plate 41.

Platinum Thermometer.

Fig: 33. *Elevation.*

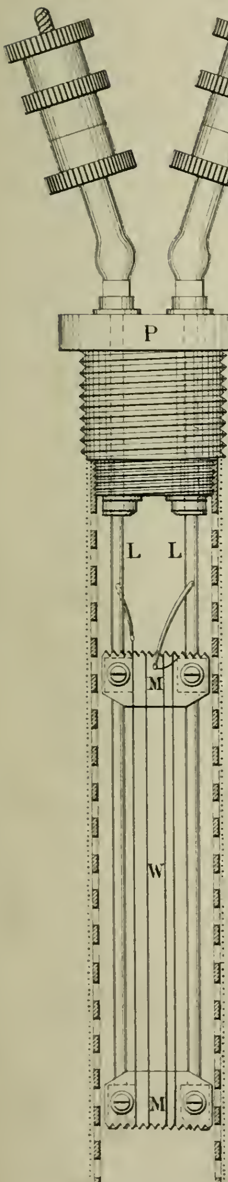
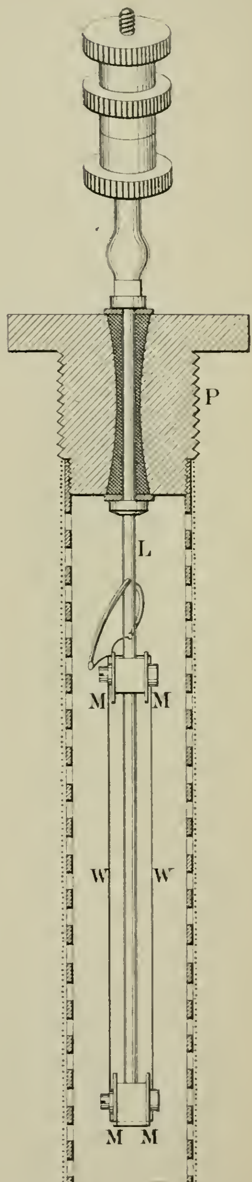


Fig: 34. *End view.*



Mechanical Engineers 1896.

Scale ¾ size

1 Inch ½ 0 1 2 3 Inches 4

STEEL STEAM-PIPES.

Roll Welding.

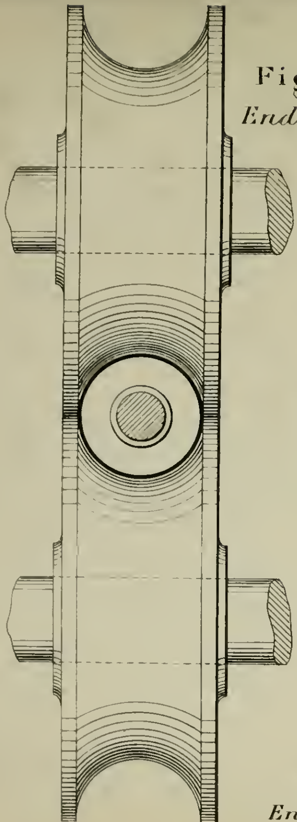


Fig. 1.
End view.

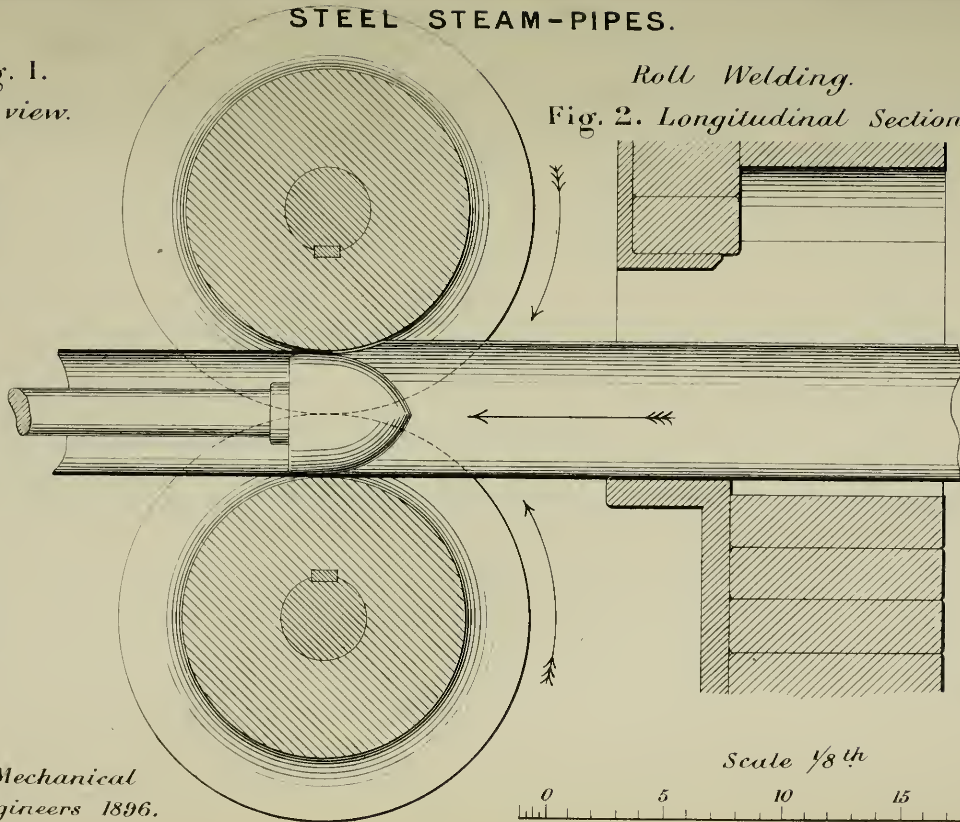


Fig. 2. Longitudinal Section.

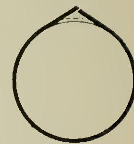


Fig. 3.
End view
of skelp.

Scale 1/8th

0 5 10 15 20 Inches

Mechanical
Engineers 1896.

Plate 43.

STEEL STEAM-PIPES.

Gas Welding.

Fig. 4. *Longitudinal Section.*

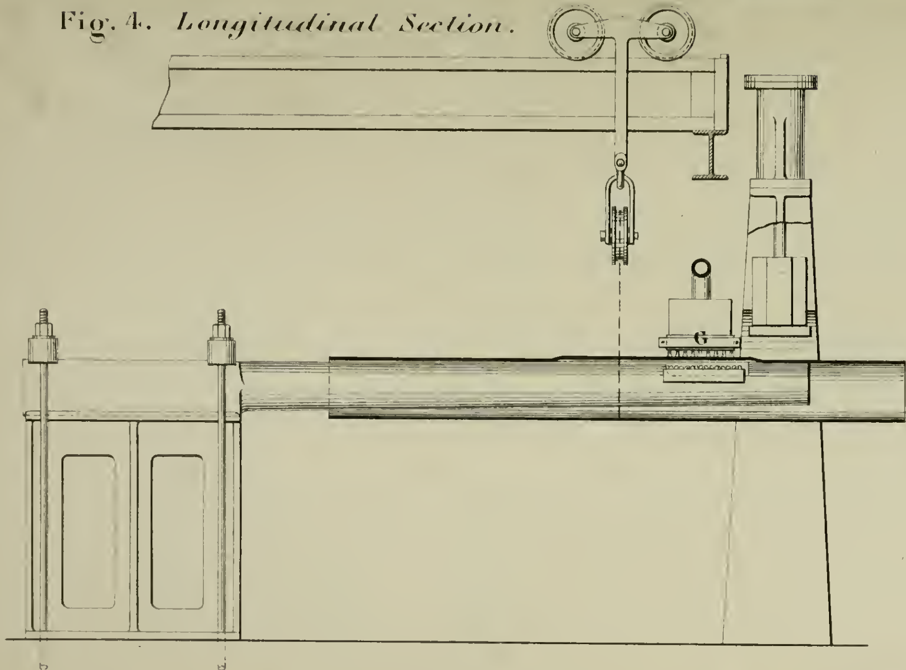
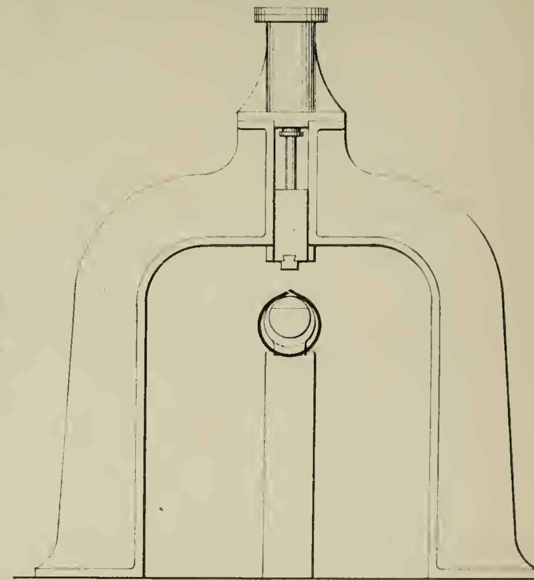


Fig. 5. *End view.*



Scale $1/32^{nd}$

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet

Fig. 6.

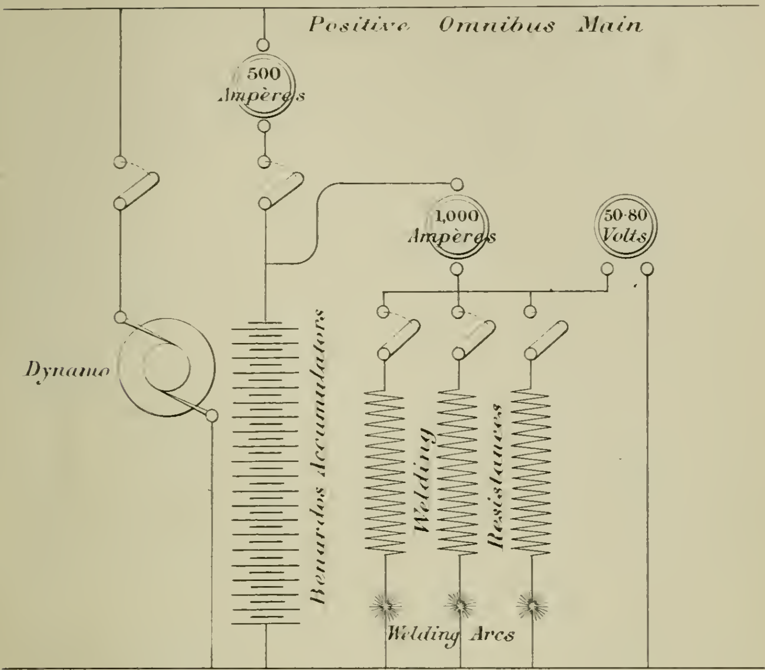


Fig. 7.

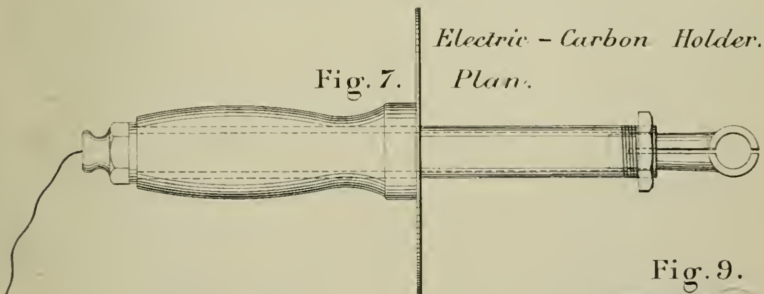
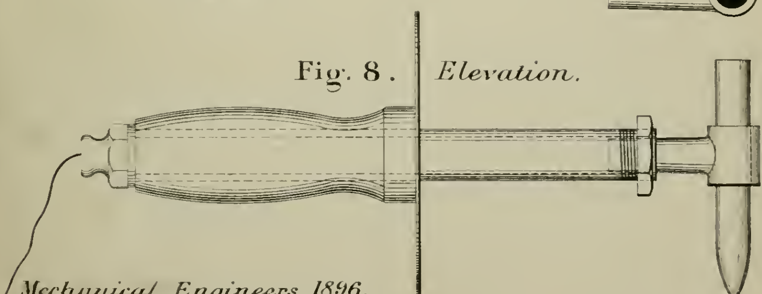


Fig. 9.

Scale 1/4 th

Fig. 8.



Flange Welding.

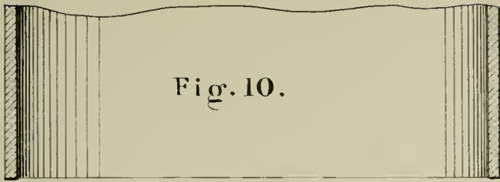
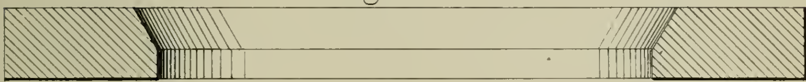


Fig. 10.

Fig. 11.



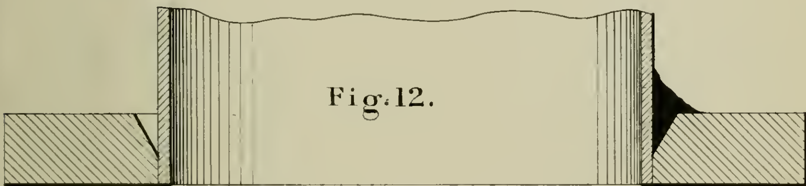


Fig. 12.

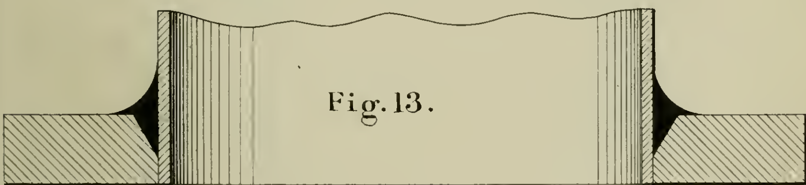


Fig. 13.

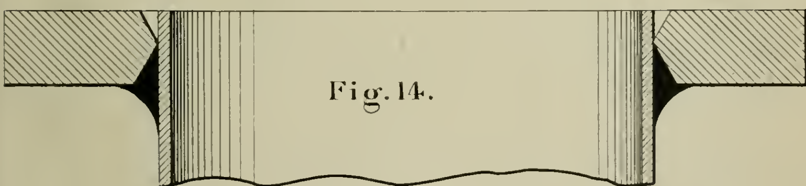


Fig. 14.

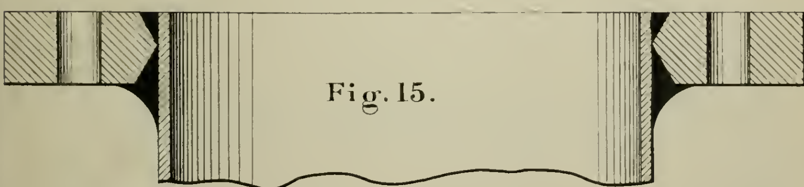
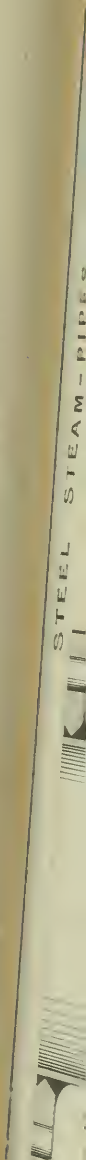


Fig. 15.

Scale 1/4 th


STEEL STEAM-PIPES

STEEL STEAM-PIPES.

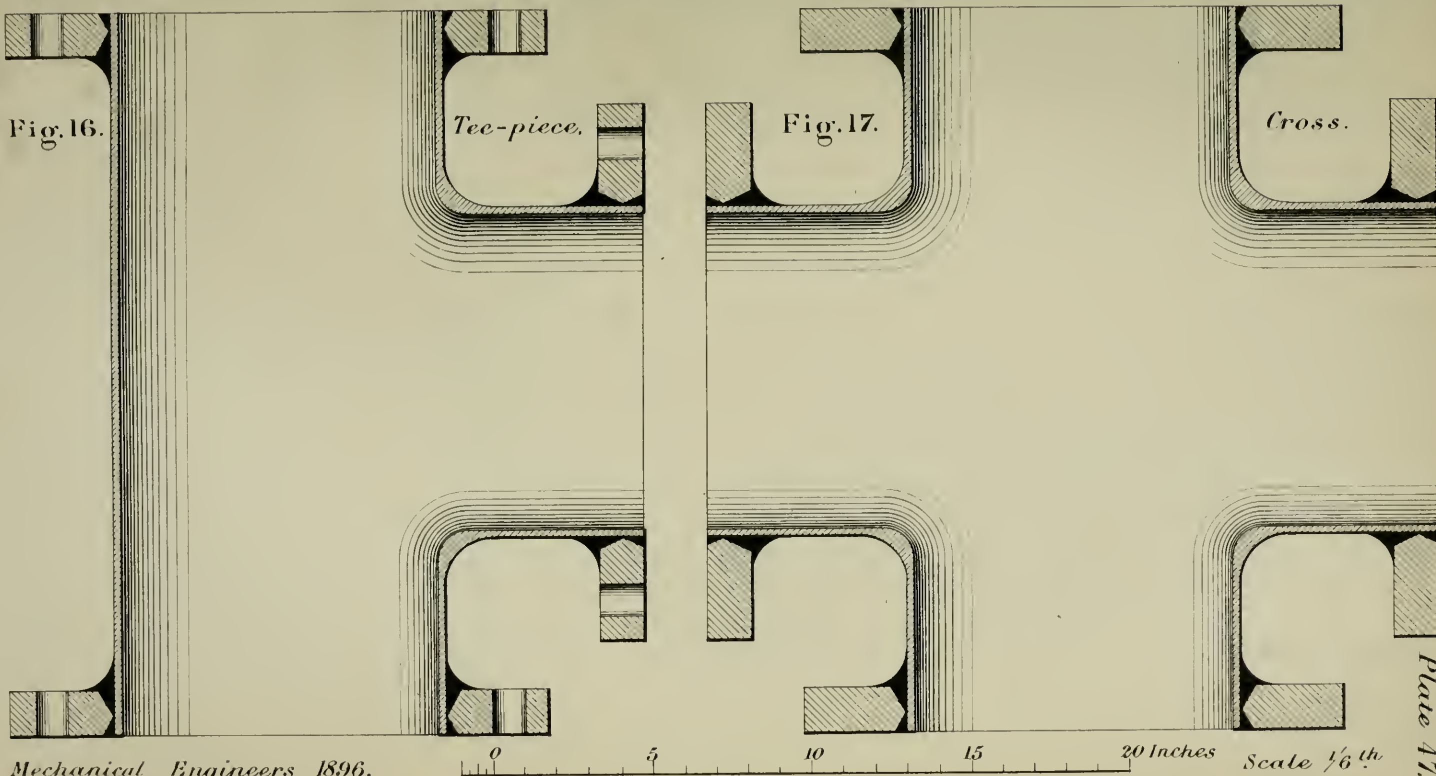


Fig. 16.

Fig. 17.

Plate 47.

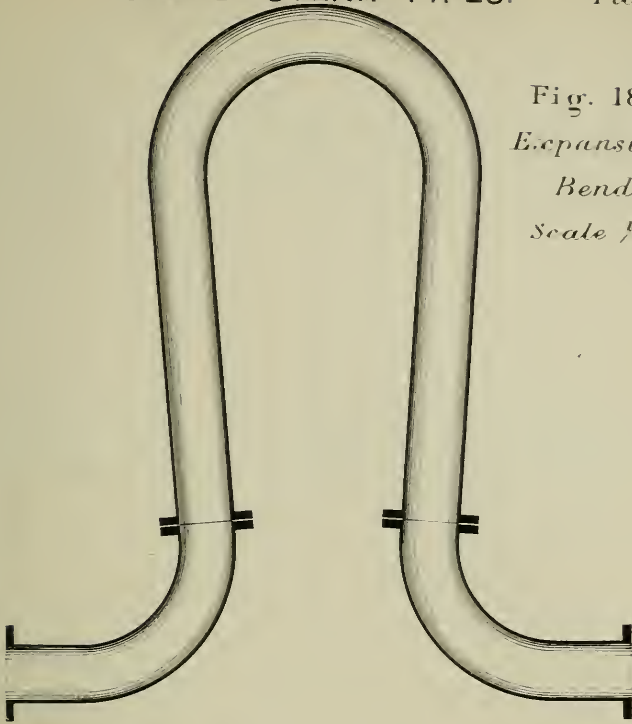
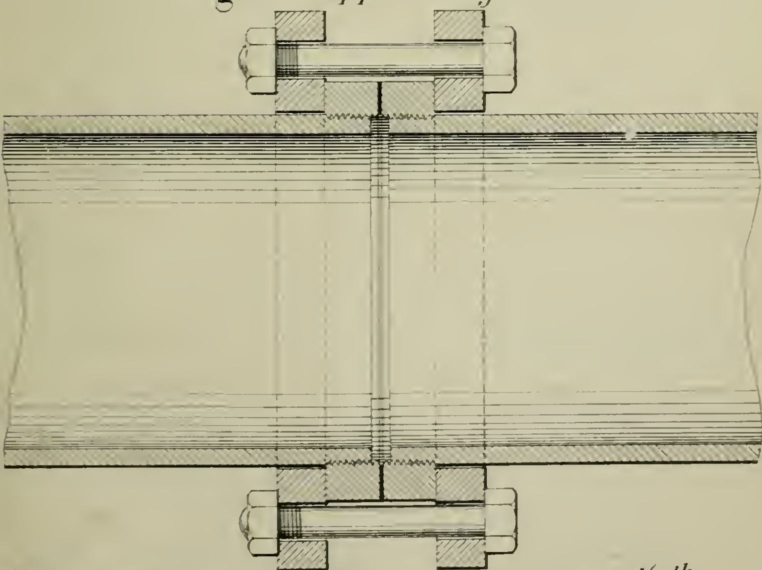


Fig. 18. *Expansion Bend.* *Scale 1/24th.*

Fig. 19. *Copper-Ring Joint.*



Mechanical Engineers 1896. *Scale 1/6 th.*

STEEL STEAM-PIPES.

Plate 19.

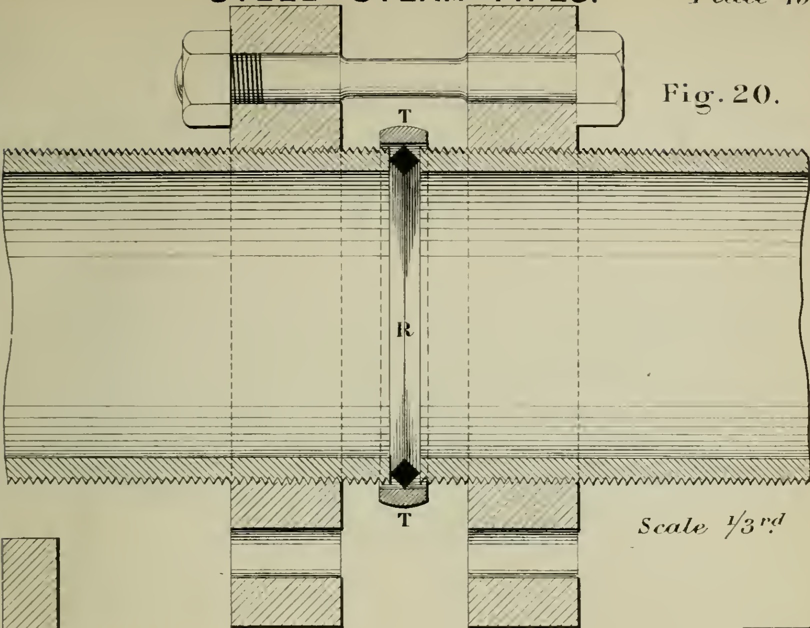


Fig. 20.

Scale 1/3rd.

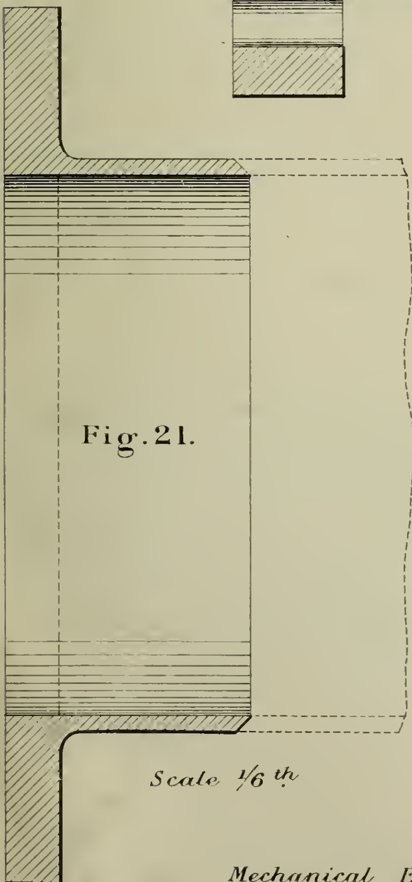


Fig. 21.

Scale 1/6th.

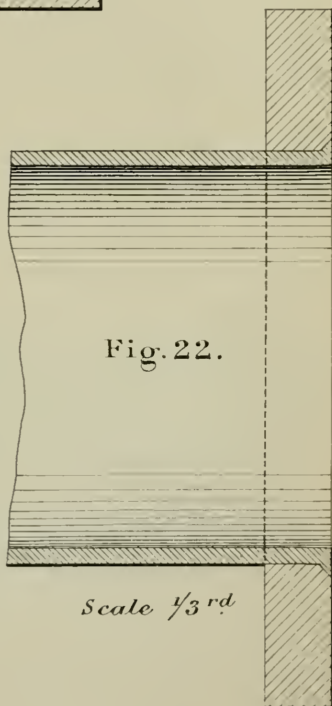


Fig. 22.

Scale 1/3rd.

Fig. 23.

Lap-welded Steel Tube.

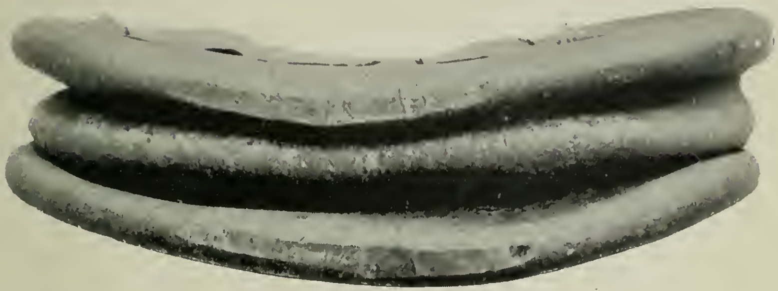


Fig. 24.

Weldless Steel Tube.

Full size.